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DESIGN STUDY OF EXPENDABLE MAIN ROTOR BLADES

Micheal C. Frengley, et al

Kaman Aerospace Corporation

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DESIGN STUDY OF EXPENDABLE MAIN ROTOR BLADES

By

Michael C. Frengley
Paul F. Maloney
Carroll R. Akeley

October 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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KAMAN AEROSPACE CORPORATION
BLOOMFIELD, CONNECTICUT

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13. ABSTRACT

A design study is performed to determine the feasibility and cost advantages of expendable main rotor blades designed for the UH-1H helicopter. Technical feasibility, manufacturing cost, reliability, maintainability, and life-cycle costs were determined. Three concepts were projected to have life-cycle costs lower than those of the current blade. A blade of simplified all-aluminum construction is shown to have the lowest initial procurement cost, while one of stainless steel sheet and fiberglass has the lowest life-cycle cost.

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This is one of a number of parallel studies examining various rotor blade design concepts emphasizing reliability and maintainability. Other concepts that have been studied are repairable and sectionalized rotor blade designs. A parallel expendable rotor blade study has been performed by Sikorsky Aircraft. These design studies are aimed at achieving considerable improvement in rotor blade R&M characteristics, thereby reducing life-cycle cost. To achieve comparability, all blade designs are required to match UH-1D/H characteristics, and life-cycle cost is compared to that for the UH-1D/H.

This study concentrated on designing a low-cost rotor blade that is more cost effective to scrap than to return for depot level repair. The design selected featured a spar assembled from formed stainless steel sheet with the afterbody fabricated from Nomex honeycomb and fiberglass skins. It was calculated that the blade life-cycle cost would be one-third less than that of the current UH-1D/H.

The cost results, although valid for comparative purposes, cannot be considered on an absolute scale. The blade design selected and the repair kits and procedures arrived at in this study must also be tested under operational conditions, as must the structural integrity of the repaired blade.

The conclusion that field-expendable rotor blade designs, as presented in this Phase I report, are cost effective is supported by the results of the parallel design study, although a different design approach was selected. A Phase II report with comparative radar cross-section measurements for simulated Design II and UH-1 rotor blades is in preparation. The results of this study and other related efforts are being considered in a recently initiated procurement for the design and development of a field-repairable/expendable rotor blade concept.

The program was conducted under the technical management of Philip J. Haselbauer, Technology Applications Division, with engineering support from Joseph H. McGarvey, Military Operations Technology Division.

Task 1F162205A11901
Contract DAAJ02-71-C-0041
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DESIGN STUDY OF EXPENDABLE MAIN ROTOR BLADFS

Phase I
Final Report

Kaman Aerospace Report R-979

by
Michael C. Frengley
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Carroll R. Akeley

Prepared by

Kaman Aerospace Corporation
Bloomfield, Connecticut

for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

SUMMARY

This report presents the results of a design study performed to determine the feasibility and cost advantages of expendable main rotor blades. The concepts investigated were designed to match the Army UH-1H helicopter parameters. The blade concepts were examined from the technical feasibility, manufacturing cost, repairability, and maintainability standpoints, all of which were integrated into an overall life-cycle cost analysis.

Four concepts were investigated, of which three were projected to have life-cycle costs lower than those of the current UH-1H main rotor blade. A blade of simplified all-aluminum construction was shown to have the lowest initial procurement cost, while one fabricated from stainless steel sheet and glass-fiber-reinforced plastic was projected to have the lowest overall life-cycle costs.

The recommendation is made that detail design be undertaken of a stainless steel and fiberglass blade, and that an evaluation quantity be built.

FOREWORD

This design study of expendable main rotor blades for helicopters was performed under Phase I of Contract DAAJ02-71-C-0041 (DA Task IF162205A11901) with the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, under the general technical cognizance of Mr. Philip Haselbauer of the Structures Division.* This expendable blade study is one of several being performed to investigate means of reducing overall rotor blade costs to the Army. Other studies cover repairable and sectionalized blade concepts.

The authors acknowledge the contributions made by Messrs. J.D. Carroll, F. Starses (who wrote, respectively, the reliability and maintainability sections), G. P. Basile, G. Halvorsen, D. H. Lathrop, F. A. Ruocco, and P. Sevenoff of the Kaman Aerospace Corporation technical staff.

*Name changed to Technology Applications Division

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LIST OF SYMBOLS

A	component cross-section area, square inches
AOT	fatigue allowable operating time, blade hours
BTBD	blade time between damage, hours
C	constant in expression for K_{BF}
C_A	attrition cost per aircraft life cycle, dollars
C_c	container cost, dollars
C_E	cost of GSE not blades per aircraft, dollars
C_m	organizational level labor rate, dollars/hour
C_{nb}	new blade price FOB, dollars
C_o	blade cost to outfit one aircraft, dollars
C_p	average repair kit price FOB, dollars
C_{RO}	organizational/intermediate level repair cost per aircraft life cycle, dollars
C_s	initial spares cost per aircraft life cycle, dollars
C_{SA}	blade air shipping cost, dollars
C_{SC}	container shipping cost, dollars
C_{so}	organizational/ intermediate level scrap costs per aircraft life cycle, dollars
C_{sp}	shipping cost of repair materials, dollars
$\overline{DT}$	mean maintenance down time, hours
E	material modulus of elasticity, psi
f	mathematical function
f	axial stress, psi
f_a	alternating component of axial stress, psi

F_A	allowable alternating stress, psi
F_E	fatigue endurance limit, psi
FH	flight time, hours
FMEA	failure mode and effect analysis
f_s	steady component of axial stress, psi
F_{tu}	ultimate tensile strength, psi
GSE	Government-supplied equipment
I_{xx}	moment of inertia about x-axis, $in.^4$
I_{yy}	moment of inertia about y-axis, $in.^4$
K_A	number of blades lost to attrition
K_{BF}	fraction of damaged blades fatigue retired
K_{BR}	overall fraction of blade damage repaired
K_{BRF}	fraction of damaged blades repaired at intermediate level
K_{BRO}	fraction of damaged blades repaired at organizational level
K_{BS}	fraction of damaged blades scrapped
K_{BSO}	fraction of damaged blades scrapped at user level
L	aircraft life cycle, flight hours
m	exponent of AOT in expression for K_{BF}
M	margin of safety
M_C	bending moment due to centrifugal force, lb-in.
MH	labor time, man-hours
M_{max}	maximum repair time, hours

MMH	maintenance labor time, man-hours
MTTR	mean time to repair, hours
M_x	moment about x-axis, lb-in.
M_y	moment about y-axis, lb-in.
M_1	MMH to inspect, disposition, remove and replace blade, man-hours
M_2	MMH to inspect and disposition damage, man-hours
M_3	MMH to inspect and disposition damage, remove and replace blade, requisition and obtain replacement, man-hours
n	exponent of K_{BR} in expression for K_{BF}
N	number of blades per aircraft
N_{bf}	number of blades damaged per aircraft life cycle
P_c	centrifugal force, pounds
t	time to repair
T_R	user repair MMH required, mean per repair, man-hours
x	coordinate parallel to x-axis, inches
X	logarithm of repair time, t, to base 10
$\bar{X}$	mean of logarithms of repair time
y	coordinate parallel to y-axis, inches
σ_x	statistical standard deviation
Σ	summation

INTRODUCTION

The cost of acquiring and maintaining a fleet of helicopters is affected in large measure by the costs associated with the main rotor blades. For a helicopter fleet operating in an area geographically remote from the rotor blade supplier and repair depot, logistic costs, particularly those associated with return for overhaul and repair, add significantly to the overall costs. The purpose of this study is to determine design concepts which will have sufficiently low initial procurement costs, in relation to their susceptibility to damage, that abandonment of a damaged rotor blade, at some level of repair short of that requiring return to a major repair depot, becomes cost-effective.

DISCUSSION

All helicopter rotor blades are repairable to some degree, but the decision whether to repair any specific external or inherent damage or to scrap the blade is dependent on a complex relationship between many factors. Logistics, cost of repair, availability of technically qualified personnel, initial cost, availability of new blades, remaining allowable service life, and reliability and performance of the repaired blade must all be considered. At the extremes of the initial cost spectrum, the decision in any specific instance is relatively clear-cut: a very expensive blade should be repaired whenever possible, whereas an inexpensive blade can be economically scrapped before making even a relatively simple repair. Because the most expedient and reliable approach is always to scrap the blade, the aim of this study is to determine methods of reducing the life-cycle cost of helicopter main rotor blades by reducing initial cost.

Any new rotor blade must meet the requirements of the helicopter on which it will be installed and of the missions on which it will be used. Although this study is general in its applicability, the validity of each concept should be tested by its suitability for a particular aircraft. Therefore, the blade concepts studied in this program are designed to be flown on the Army UH-1H helicopter, and all the significant design parameters have been chosen to meet this objective. The present UH-1D/H main rotor blade provides the basis of comparison for the blade weight, strength, bending stiffnesses in- and out-of-plane, natural frequencies, static and dynamic bending moments, static droop, mass balance, centrifugal loads, and aerodynamic characteristics. The minimum deviation from these characteristics has been sought for each of the concepts studied.

The first step to take in cost reduction is in the direction of simplification. For this reason, minor differences, particularly in the distribution of section properties, have been considered acceptable. The airfoil contour of three of the four concepts studied has been simplified by moving the maximum thickness location forward to allow for straight flanks over most of the aft section, but the effect on aerodynamic characteristics will be negligible. In all of the concepts, no taper or straight structural tapers have been incorporated, avoiding structural steps and discontinuous components, significantly reducing the number of detail parts. In all of the concepts except the fourth, which was discarded for other reasons before completion of the study, the overall mass, inertia, balance, and static properties of the UH-1H main rotor blade have been almost, but not exactly, equalled. The minor refinements required to finalize the overall properties are considered more properly accomplished in the detail design phase than in a conceptual study such as this. Detail changes, such as the addition of tip weights, are shown to have sufficient effect that all desired characteristics can be achieved without difficulty. Because of design differences, particularly in spanwise mass distribution, it is impractical to equal all the physical parameters of the present blade. For example, although it is possible to duplicate the total weight and the first moment about the center of rotation (and consequently, the centrifugal force), the second moment will be slightly different. Such minor changes will not affect flying qualities.

This same limitation applies to the method proposed for achieving dynamic interchangeability between the blades in a production series, since the blades can only be mass balanced to correct two of the design parameters. Again, however, the slight variations in the other parameters arising from manufacturing tolerances will have no effect on flying qualities, and will, in fact, be at least as close as is typical of any rotor blade production series, including the current UH-1H blades. Mass balance is corrected during production by the adjustment of two variable weights in the tip, forward and aft of the mass axis. The same variable weights can be used to correct the balance after minor repairs.

Early in the study, it became apparent that a completely expendable blade would be impractical. No matter how inexpensive the blade, there would always be some minor damage which could be blended out, filled, or painted over with such small effort that abandonment of the blade would be uneconomic. It was decided, therefore, that the level of expendability would be limited to damage sufficiently extensive to require return to a fully equipped repair depot. Those repairs which could be performed in the field, either at the organizational or intermediate maintenance level, with normally available personnel, tools, and materials, were considered acceptable. For the three blade design concepts for which this study is completed, a repairability study is therefore included.

Since the frequency of repair or scrappage is a significant factor in the overall life-cycle costs, a survivability analysis has been performed. Any design features which could be expected to have a deleterious effect on reliability were avoided, if possible, in each of the design concepts.

The life-cycle costs have been derived based on these basic factors of initial cost, survivability, and repairability. The three design concepts studied to completion are compared on this basis with each other and with the present UH-1D/H main rotor blade.

ANALYSIS METHODOLOGY

The detail analysis performed on each of the concepts evaluated consists of four phases: the technical analysis (section properties, weight and balance, dynamic loads and moments, and stress analysis), the reliability analysis, the maintainability analysis, and a life-cycle cost analysis which synthesizes the results of the previous analyses into a presentation of the cost per blade for the operational life of a fleet of helicopters. Integrated into the life-cycle costs are the manufacturing costs associated with each design concept. One design concept proved to have prohibitively high manufacturing costs and was dropped from the study before initiation of the reliability analysis phase.

Technical Analysis

The contractor's standard computer program was used to generate the mass and stiffness properties of the significant cross sections of each design. This program accepts a series of coordinates describing points on the boundary of each component, and generates the geometric properties (area, centroid, and first and second moments of area about a pair of orthogonal axes, and the product of inertia about these axes) of the component section. These geometric properties are then multiplied by the respective material weight densities and summed, giving the total section weight and inertia per unit length and section center of gravity, and by the respective material moduli of elasticity, which are summed for the total section axial and bending stiffnesses and the neutral axis. For unsymmetrical sections, the mass and stiffness principal axes can be determined by equating the mass and stiffness products of inertia to zero. All four design concepts, however, have symmetrical airfoil sections, while only Design 3 has slightly unsymmetrical internal structure. The chord plane, therefore, lies along one principal axis in three concepts and is insignificantly displaced from it in Design 3.

The section properties so generated were then introduced into the contractor's standard dynamic analysis programs, and natural frequencies and dynamic (flight) bending moments were determined. Integrated blade weight and balance and static bending moments and deflections were found using another computer program.

Finally, standard plane section stress analysis techniques utilizing the section properties and dynamic bending moments were used to determine flight stresses and fatigue margins of safety, as described in the stress analysis section.

Reliability Analysis

The reliability and survivability of Designs 1, 2, and 3 were evaluated using the known history of the current UH-1D/H main rotor blades as a base (Table H-I of Reference 2). The incidents in the reference were expanded to provide a failure modes and effects analysis for the current blade (see Appendix I), and the number of occurrences of each incident was adjusted to agree with those given in the reference.

The failure modes and effects analysis generated for the current blade was then modified for each of the expendable design concepts, by adjusting for the known and anticipated characteristics of the materials and details specified for each design.

The relative survivability characteristics of each of the three expendable concepts could thus be compared with each other and with the current UH-1D/H main rotor blade.

Maintainability Analysis

Each of the types of damage investigated and evaluated in the failure modes and effects analyses was examined to determine its repairability. This examination determined the ultimate disposition of each damage incident: whether it should be repaired at the organizational or intermediate level, or whether it should be scrapped.

For those types of damage for which a repair was considered acceptable, the man-hours to perform the repair and the material costs associated with them were generated. From these figures and those for scrappage, the maintenance costs per unit of blade and aircraft life were determined.

Life-Cycle Costs

For each of the three acceptable expendable blade design concepts, the manufacturing labor, material, and burden costs were analyzed, and the initial cost of varying production quantities at varying rates of production was determined for each design. These costs were obtained on a basis comparable with that for the current blade. The 10,000th unit was used for the comparison.

These initial costs (to the Army) were combined with maintenance, replacement, and attrition costs to give the total life-cycle costs, using the cost model below.

Cost Model

The cost model proposed to develop expendable blade program costs is shown schematically in Figure 1. The model is arranged to generate costs per aircraft life cycle in the following three categories:

1. Initial Costs
2. Operating Costs
3. Attrition Costs

It should be noted here that attrition in this program is used to denote blades lost to other than blade damage events, and is included to provide a realistic appraisal of the total blade requirement during the program life cycle.

Input data for the cost model consists of a given expendable blade design concept and a distribution of external blade damage events supplied by the Army as shown in Appendix I. A reliability failure modes and effects analysis for each blade design concept determines the blade time between inherent and external damage and the disposition of blade damage. A maintainability analysis provides the repair times, repair procedures and repair kit contents and costs. Standardized blade cost model input values supplied by the Army, such as aircraft life, external blade damage distribution, shipping costs, and maintenance cost per man-hour, are applied along with contractor-generated inputs such as new blade costs, repair criteria, kit costs, and repair man-hours to determine life-cycle program costs.

Model Input Data

Cost factors that vary with expendable blade design concepts are defined as follows:

C_{nb} = Cost of a new blade FOB

C_p = Cost of repair kit FOB

C_E = Cost of any GSE required per aircraft

T_R = User repair MMH required, mean per repair

AOT = Allowable blade operating time due to fatigue criteria, blade hours

K_{BRO} = Fraction of damaged blades repaired at organizational level

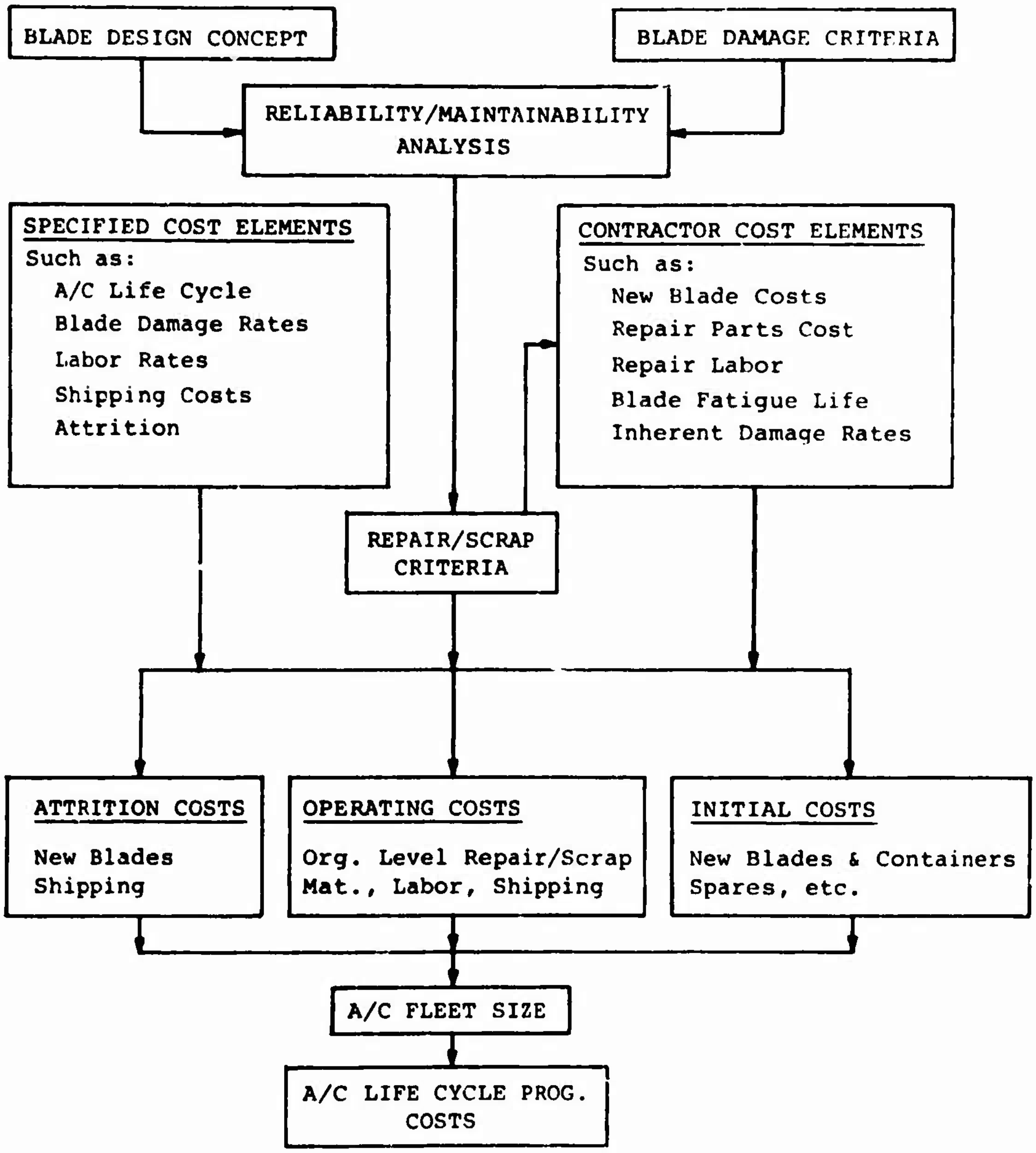


Figure 1. Expendable Blade Cost Model Schematic.

K_{BRF} = Fraction of damaged blades repaired at the intermediate level

K_{BSO} = Fraction of damaged blades scrapped at the user level

Additional life-cycle cost elements common to all blade designs are incorporated into the following cost equations.

Aircraft Life-Cycle Blade Damage

$$N_{bf} = \left(\frac{N.L}{BTBD} - N\right)$$

N_{bf} = Number of blades damaged per aircraft life cycle

N = Number of blades per aircraft

L = Aircraft life cycle, flight hours

$BTBD$ = Blade time between damage, blade hours

1. Initial Costs

These consist of blade costs to equip production aircraft and provide spares.

a. Aircraft Outfitting

Only the FOB price of the new blades is considered here. Other costs such as preparation and installation are small compared to the new blade costs and are neglected since they occur only once in the aircraft life cycle.

$$C_o = N.C_{nb}$$

where C_o = Blade cost to outfit one aircraft.

b. Spares

Since the cost model is not time phased but considered as a single 10-year life-cycle analysis, initial spares costs are developed to reflect blade repairability during the aircraft life cycle as opposed to using a given percentage of installed blades. For this analysis, operating spares are accounted for by operating cost elements described later. In order to fill the initial spares requirement, all blades scrapped over a six-month period must be procured to maintain the system. Since the aircraft life cycle is 120 months, a six-month requirement is 1/20 of that for the aircraft life cycle and the initial spares cost is

$$C_s = \left[N_{bf}/20\right] \left[(K_{BS}+K_{BF})(C_{nb}+C_c+C_{SA}) + (K_{BRO}+K_{BRF})(C_p C_{sp})\right] + C_E/20$$

where C_s = Initial spares cost per aircraft life cycle

K_{BS} = Fraction of damaged blades scrapped

K_{BF} = Fraction of damaged blades fatigue retired*

C_c = Container cost

C_{SA} = Blade air-shipping cost

C_{sp} = Shipping cost of repair parts as a fraction of cost

Combining the cost to outfit production aircraft with the initial spares cost yields

$$\text{Initial Cost} = C_o + C_s$$

---

*Estimate of fraction of blades fatigue retired - Data from Reference 1 shows that for the UH-1D/H, 1.06% of the damaged blade removals were due to reaching an allowable operating time of 2500 hours. For the AH-1G/UH-1C aircraft, 4.76% of the removals were due to reaching an AOT of 1100 hours. In addition, assuming that when the average blade operating time per aircraft life cycle reaches the allowable operating time, scrap damage must be zero or, conversely, the blade is fully repairable. This provides a set of data with variations in both repairability and AOT.

2. Operating Costs

As shown in the cost model schematic, operating costs consist of:

Organizational/intermediate level cost of blade damage repair.

Organizational/intermediate level cost of blade damage scrap.

When a failure modes and effects analysis is applied to the expendable blade candidates, the fraction of blades damaged for each of the above categories is determined. Operating costs are then developed based on a maintainability analysis of replacement parts cost, labor costs and shipping associated with each category as follows:

a. Organizational/Intermediate Repair Cost

$$C_{RO} = N_{bf}\left[C_m(M_1+T_R)K_{BRF}+C_m(M_2+T_R)K_{BRO} + (C_pC_{sp})(K_{BRF}+K_{BRO})\right] + C_E$$

where C_{RO} = Organizational/intermediate level repair cost per aircraft life cycle

C_m = Organizational level labor rate

M_1 = MMH to inspect, disposition, remove and replace a blade

M_2 = MMH to inspect and disposition damage

The above expression allows costs to be determined for damage repair on the aircraft (K_{BRO}) and with blades removed (K_{BRF}).

b. Organizational/Intermediate Level Cost of Blade Scrap

The analysis assumes that every effort will be made to scrap at the user level both excessively damaged blades and those that have reached their fatigue life limit.

$$C_{so} = N_{bf} \ (K_{BSO}+K_{BF}) \ \left[C_{nb}+C_{SA}+C_{SC}+C_m(M_3)\right]$$

where C_{so} = Organizational/intermediate level scrap costs per aircraft life cycle

C_{SC} = Container shipping cost

M_3 = MMH required to inspect and disposition damage, remove and replace blade, and requisition and obtain replacement

Assuming $K_{BF} = f\left\{\left(\frac{K_{BR}}{AOT}\right)\right\} = C\ (K_{BR})^n \big/ (AOT)^m$ and

utilizing the data from above to resolve the constants,

$$K_{BF} \approx 27\ (K_{BR})^{1.395} \big/ (AOT\times 10^{-2})^{1.835}$$

where K_{BR} = Overall fraction of blade damage repaired

3. Attrition Costs

These costs are considered in addition to program costs resulting from blade damage events as noted earlier. Since the blade may be used at the airframe origin, the depot level, or in the field, the only attrition costs used here are for the new blade and assumed transportation.

$$C_A = K_A\ (C_{nb} + C_{SA})$$

where C_A = Attrition cost per aircraft life cycle

K_A = Number of blades lost to attrition

Summation of initial, operating and attrition costs provides a reasonable measure of blade program costs during the life cycle of the aircraft. There are other cost elements involved in the total program that are not included in this model because they are not readily available and because their effect is relatively minor. Some of these are:

Performance degradation due to repair.

Facilities and equipment not presently envisioned.

Shipping costs from one user location to another.

Total program costs are readily generated knowing life-cycle cost per aircraft and applying it to the desired fleet size.

DESIGN CONCEPTS

The four design concepts which were examined during this program are shown in Figures 2 through 5. These concepts were chosen because the number of component parts is minimized and the components themselves are simplified; thus, the first cost of the delivered blade will be sufficiently low that it will be cost-effective to scrap a damaged blade rather than to return it for repair. The susceptibility to external and inherent damage of the various blade and component designs and materials was considered in the light of possible trade-off between first cost and service life. Table I presents the design features of each concept.

Design 1

This concept is illustrated in Figure 2 and is the closest to conventional current practice of the four under study. It consists of an extruded aluminum alloy spar, aluminum alloy aft skins supported by aluminum honeycomb core, and an aluminum alloy extruded trailing-edge spline, assembled by adhesive bonding. To minimize the number of parts, the spar is extruded with relatively heavy walls, and with the nose portion of considerably heavier thickness to provide integral section balance.

To facilitate carving of the aft core, the airfoil section is modified from that used for the current blade. The basic 12% thickness of the 21.0-inch cord is retained, but the ordinates of the forward 42% of the airfoil are those of an NACA 0015 section on a 16.8-inch chord. Straight lines are then drawn tangent to this contour to complete the airfoil at 21.0 inches. The primary effect of this modification is to allow straight line carving of the aft core, by bandsaw or similar simple method; this advantage is the reason for choosing the modified airfoil. In addition, the forward location of the maximum thickness and the larger ordinates close to the nose make the section easier to balance. Aerodynamically, the slightly increased curvature in the region of maximum thickness will lower the critical Mach number, but because the overall thickness ratio is not increased, this effect will be small. On the other hand, the increased nose radius will increase the maximum lift coefficient, allowing a minor reduction in tip speed to compensate for the reduced critical Mach number. Both effects are expected to be negligible, however, so that the net effect on performance will be well within tolerance even with no change in rotor speed, and will be far outweighed by the reduction in design and manufacturing complexity.

A

DESIGN CONSIDERATIONS

1. AIRFOIL SECTION MODIFIED TO PROVIDE STRAIGHT-SIDED AFT SECTION.
2. CONSTRUCTION SIMILAR TO PRESENT UH-1 BLADE.
3. CONSTANT SECTION EXTRUDED SPAR.
4. LIMITED VARIATION IN SECTION PROPERTIES.
5. STRAIGHT-SIDED HONEYCOMB CORE FOR SIMPLE CARVING.

FABRICATION

1. PROCESSING SAME AS PRESENT BLADE.

RELIABILITY AND MAINTAINABILITY

1. THICK LEADING EDGE TOLERANT OF ABRASION DAMAGE.
2. LEADING EDGE READILY BLENDED TO REMOVE DAMAGE.
3. DAMAGED AFT SECTION CANNOT BE REPAIRED IN FIELD.

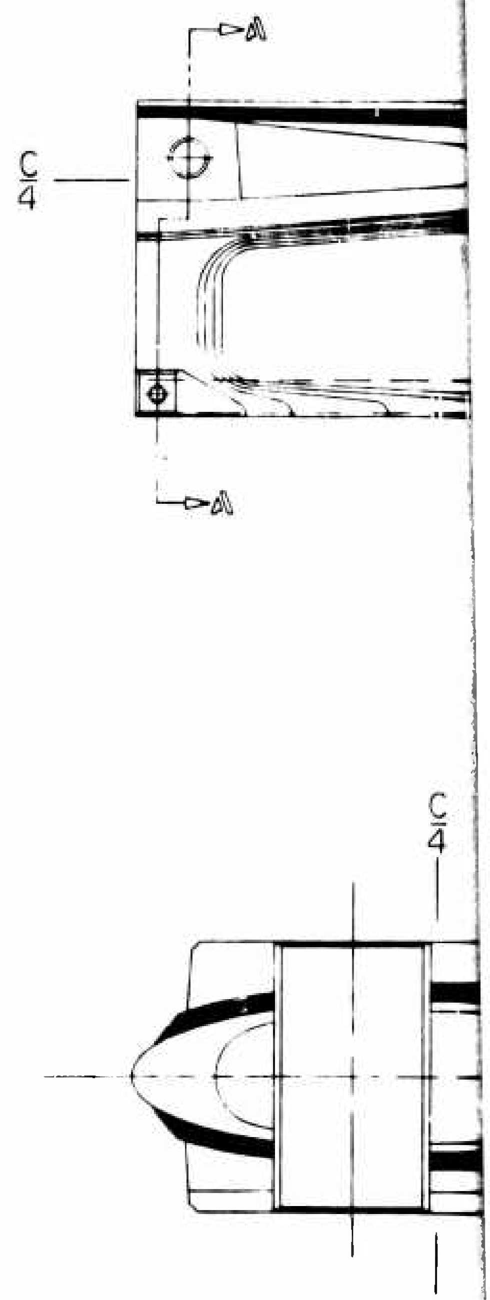
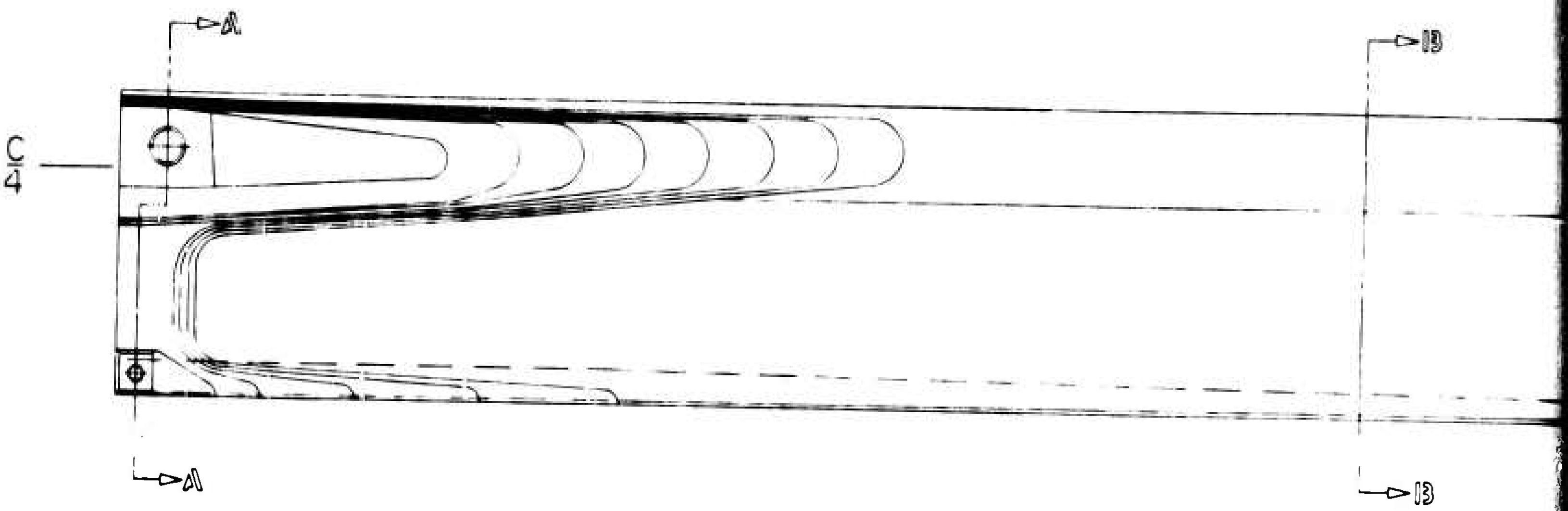
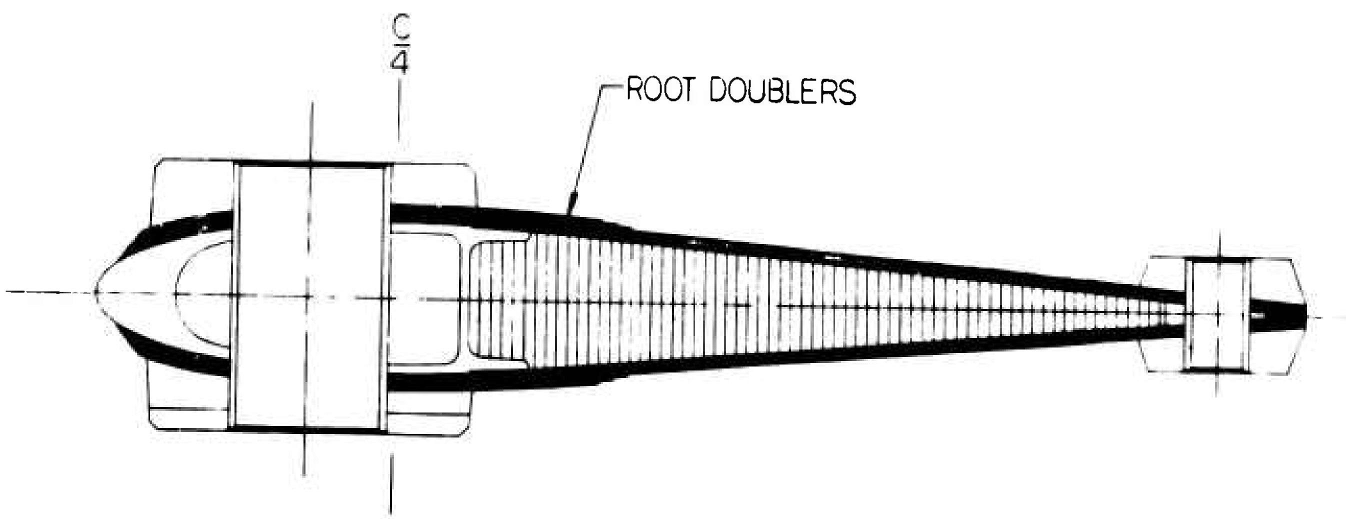


Figure 2. Design 1, Expendable Rotor Blade, All-Aluminum Structure.

B



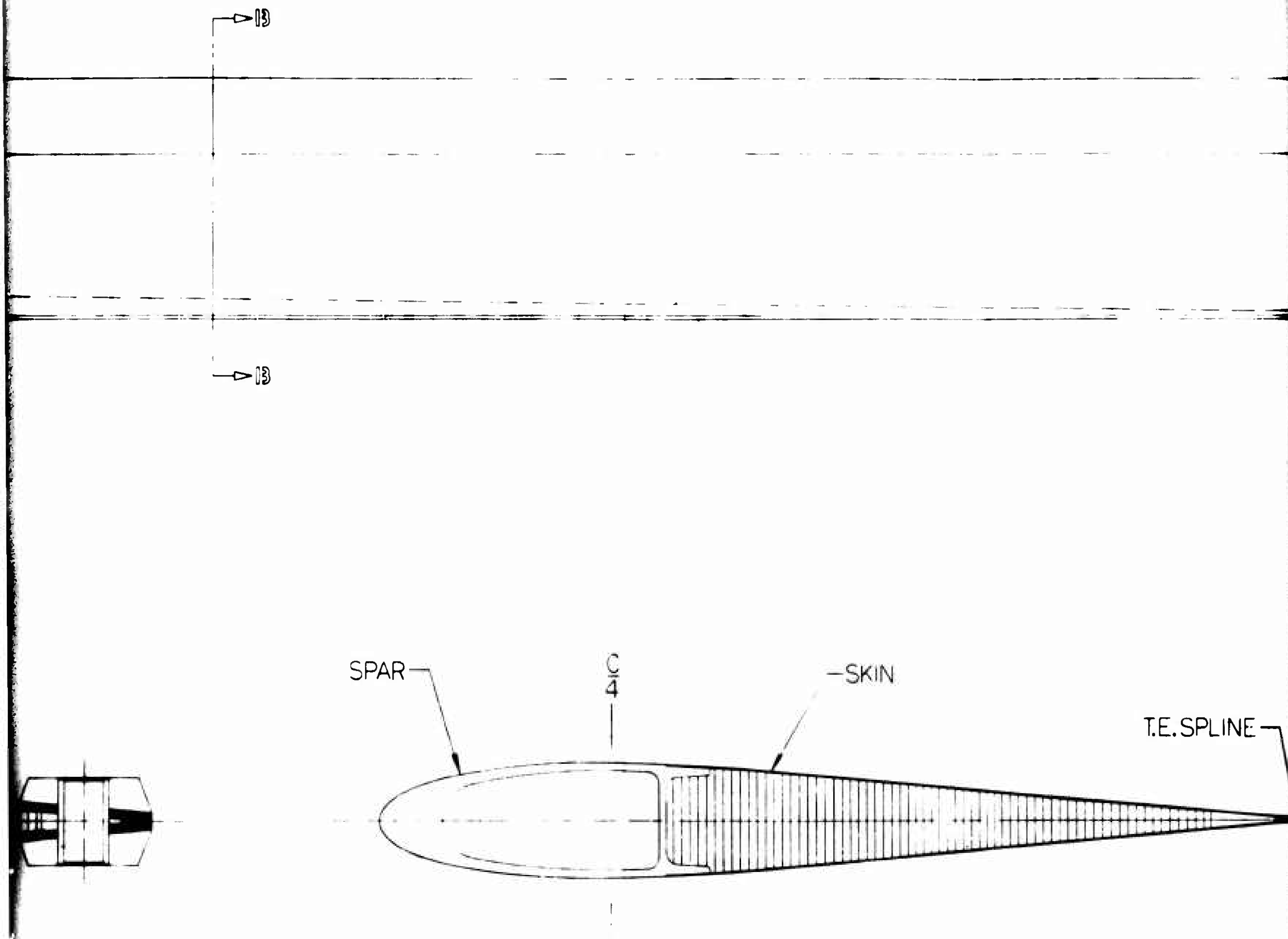


SECTION A-A

SP

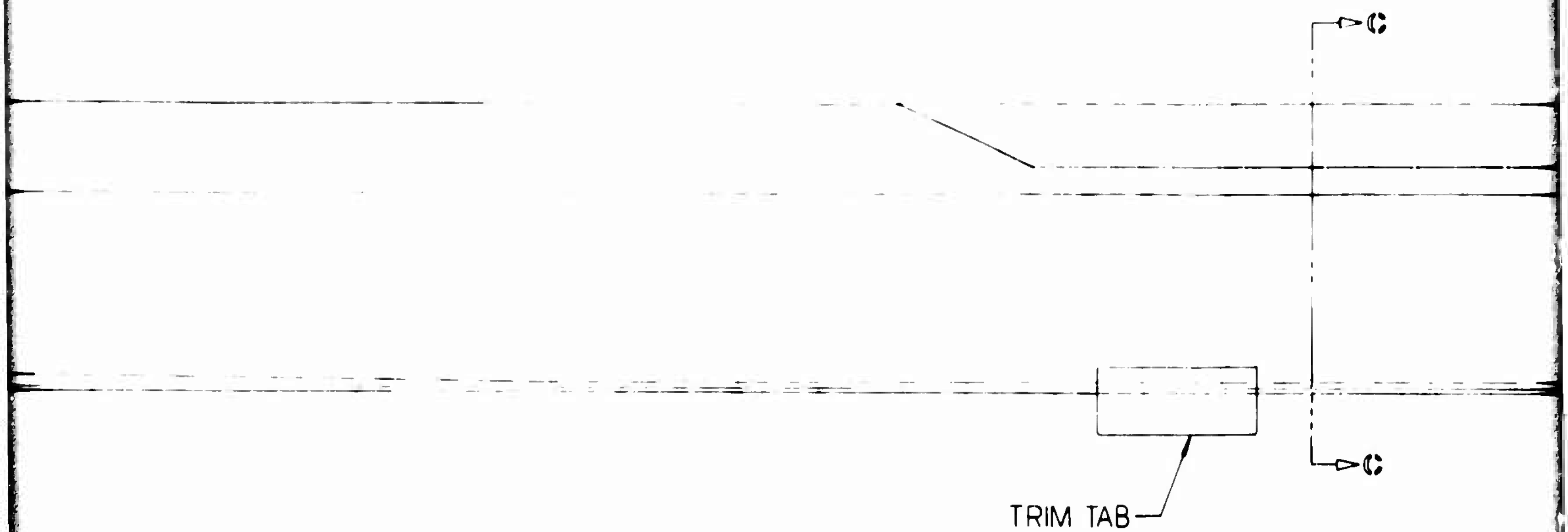
lade,

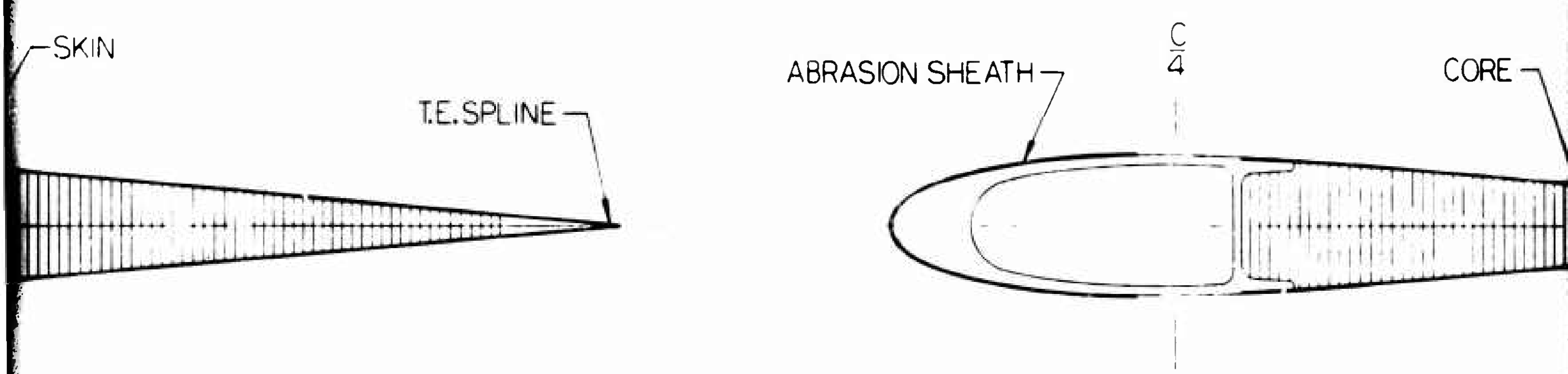
C



SECTION B-B

D





SECTION C-C

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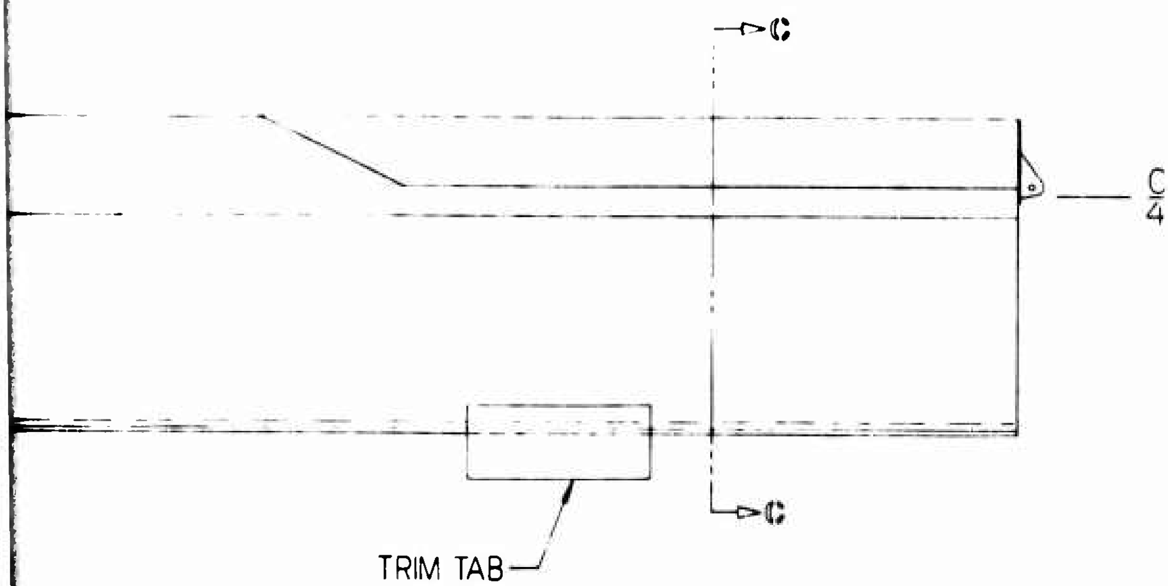

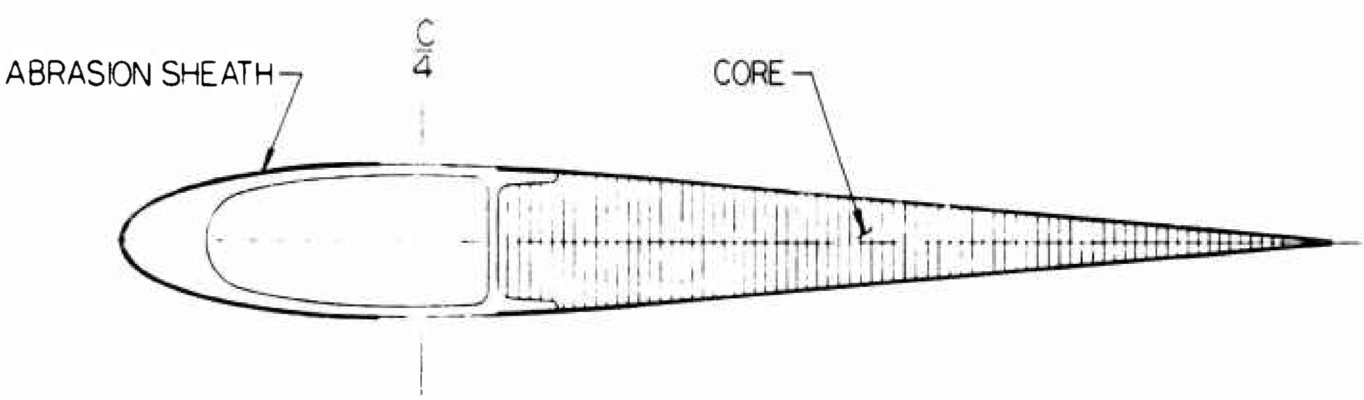

SECTION C-C

A

DESIGN CONSIDERATIONS

1. AIRFOIL SECTION MODIFIED TO PROVIDE STRAIGHT-SIDED AFT SECTION.
2. SPAR ASSEMBLED FROM SIMPLE FORMED STAINLESS STEEL SHEET.
3. UTILIZES EXISTING RETENTION.
4. GLASS FIBER REINFORCED AFT SECTION TO MINIMIZE STRESSES DUE TO BONDING TEMPERATURES.
5. SECTION PROPERTIES TAPERED TO MATCH PRESENT UH-1 BLADE.
6. PRETWIST OF SPAR COMPONENTS NOT REQUIRED
7. INTRODUCTION OF AIRFOIL VARIATIONS POSSIBLE.
8. AFT SKINS LOCALLY THICKER UNDER ROOT DOUBLERS.
9. LIGHTWEIGHT "NOMEX" HONEYCOMB CORE WITH STRAIGHT SIDES FOR SIMPLE CARVING.

FABRICATION

1. AFT SKINS AND TRAILING EDGE SPLINE LAID UP AND CURED SEPARATELY.
2. FINAL BONDING SIMILAR TO PRESENT BLADE.

RELIABILITY AND MAINTAINABILITY

1. INHERENT ABRASION RESISTANCE WITH STAINLESS STEEL SPAR.
2. RUGGED DAMAGE-RESISTANT SPAR.
3. AFT SECTION REPAIRABLE IN FIELD.
4. HIGH FATIGUE RESISTANCE.

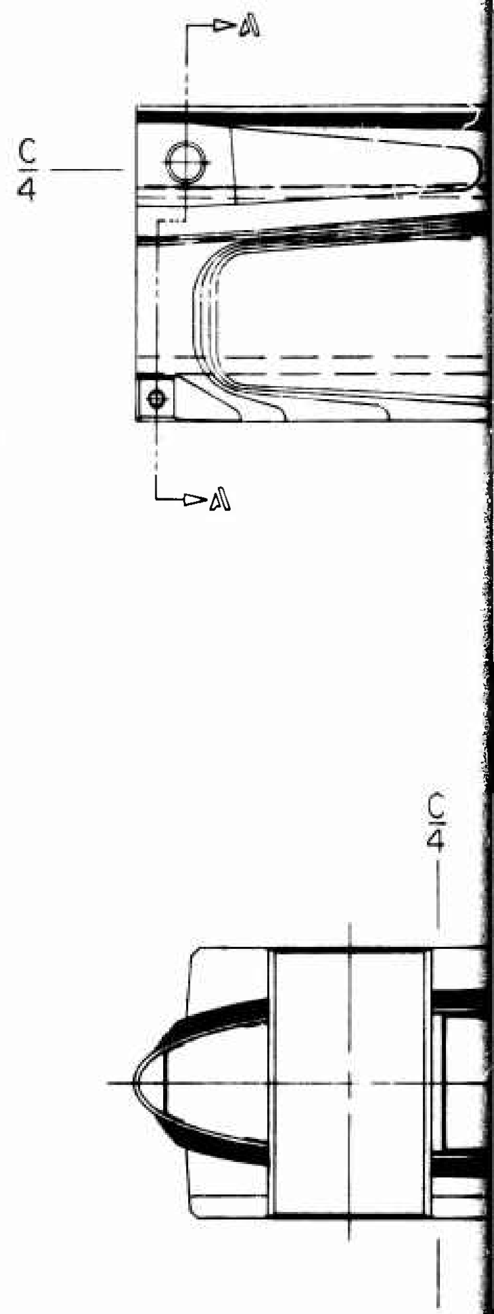

Figure 3. Design 2, Expendable Rotor Blade, Formed Sheet Metal Spar.

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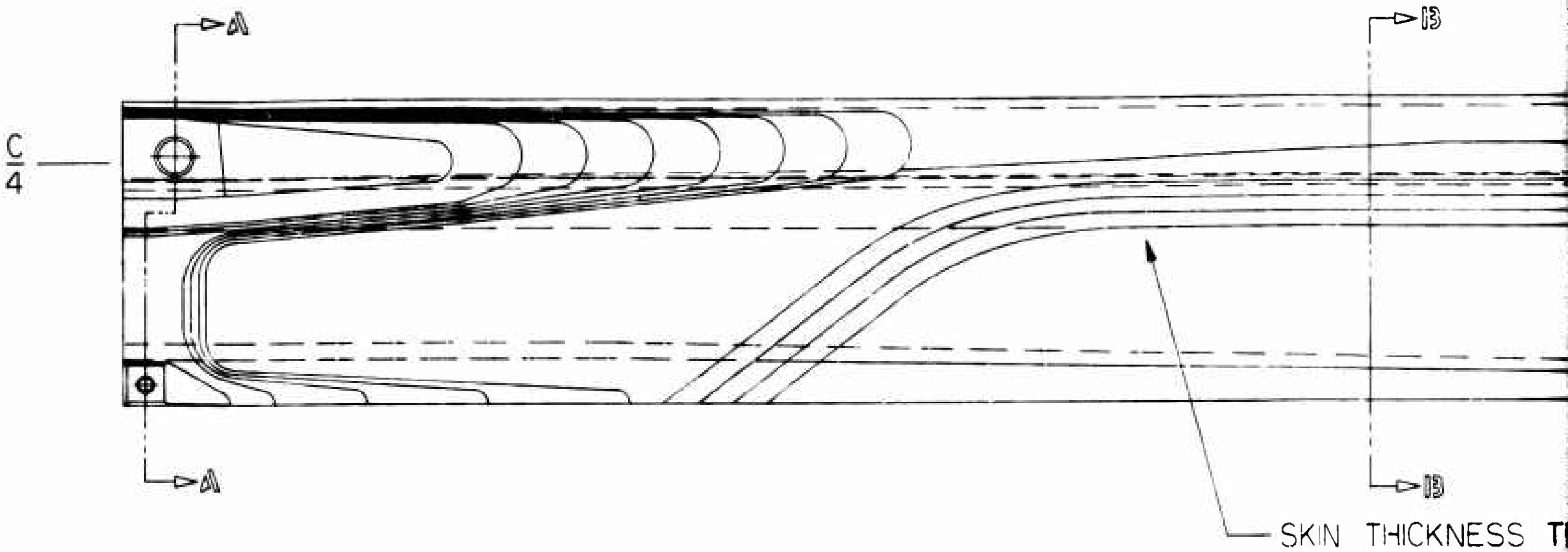
B



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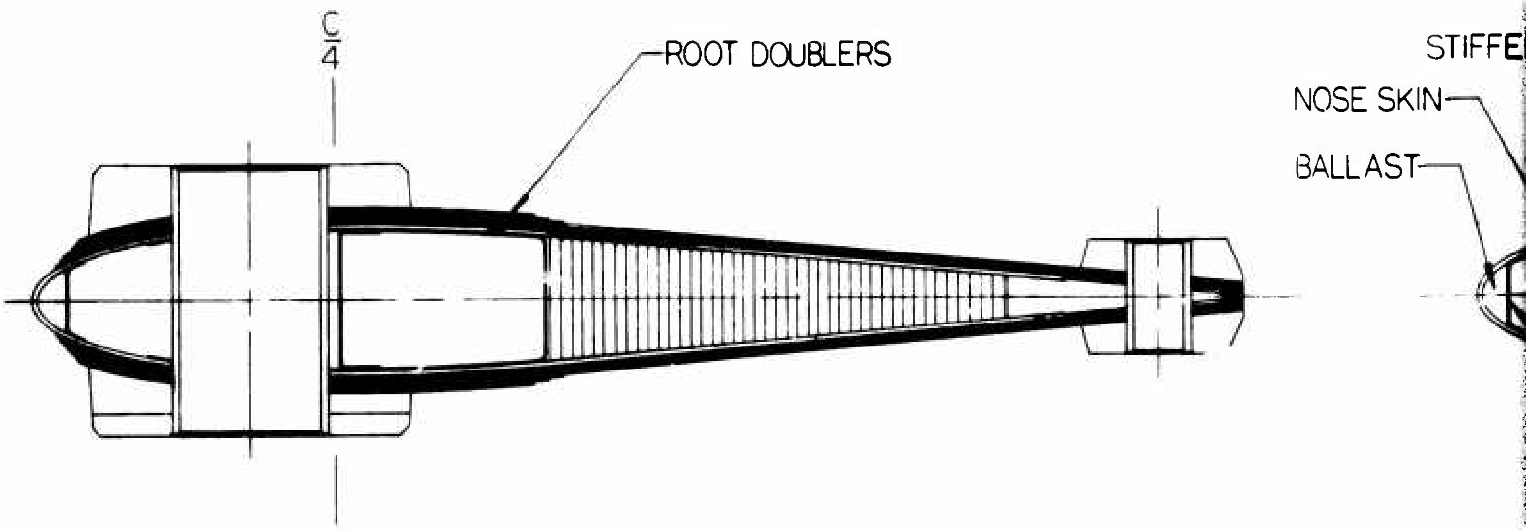

SECTION A-A

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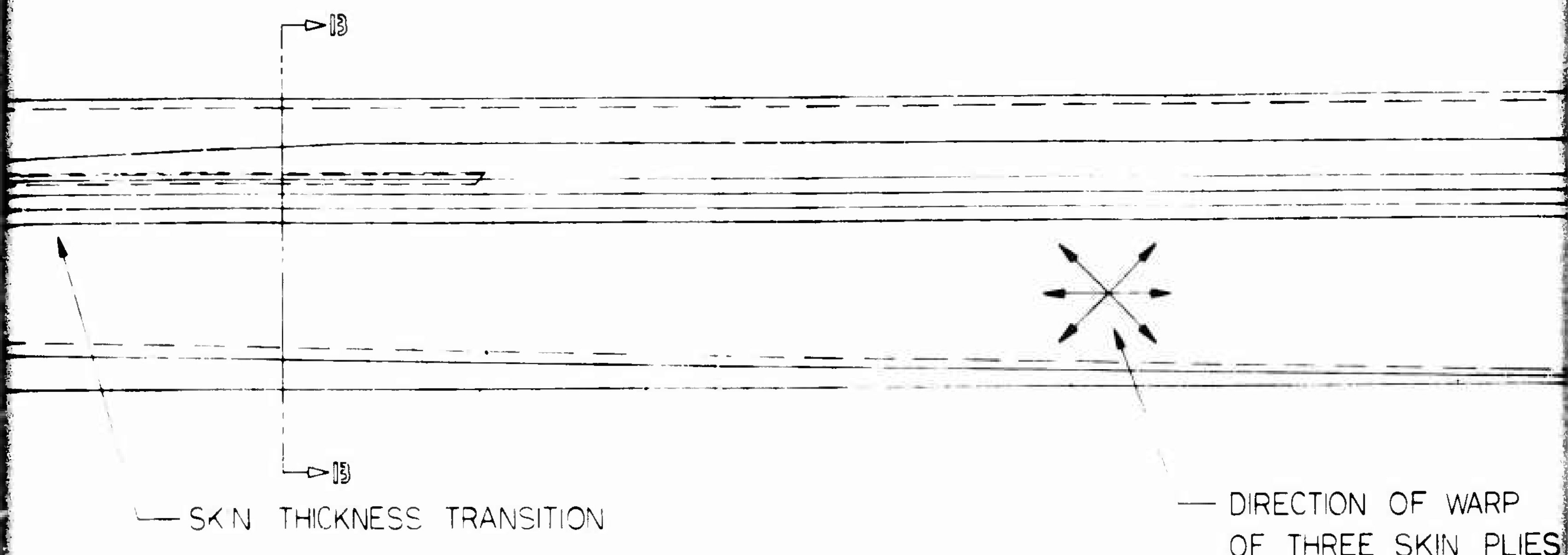
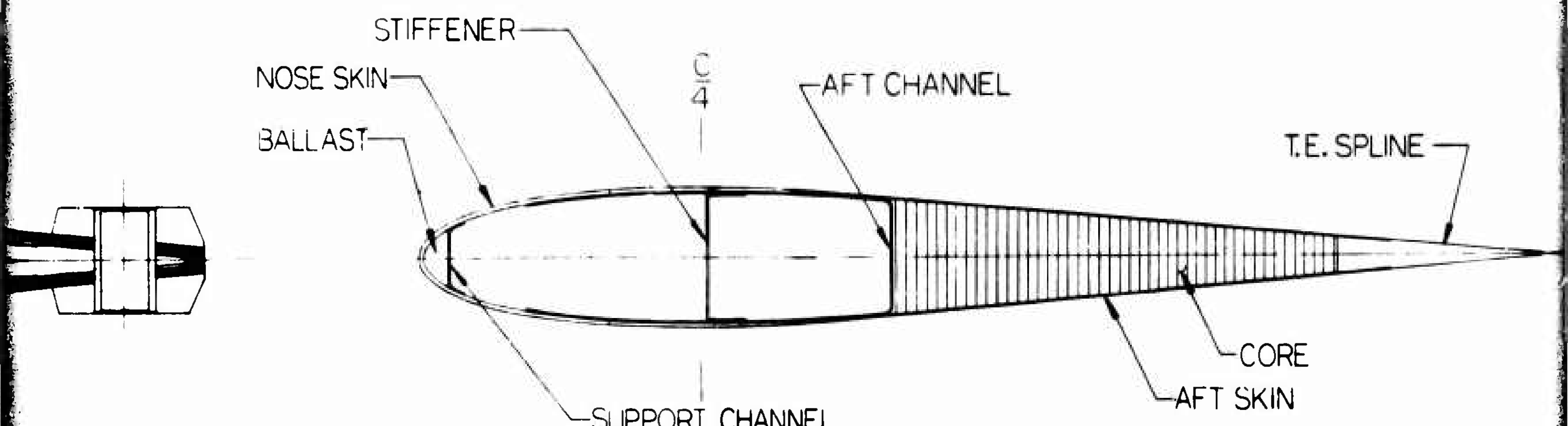


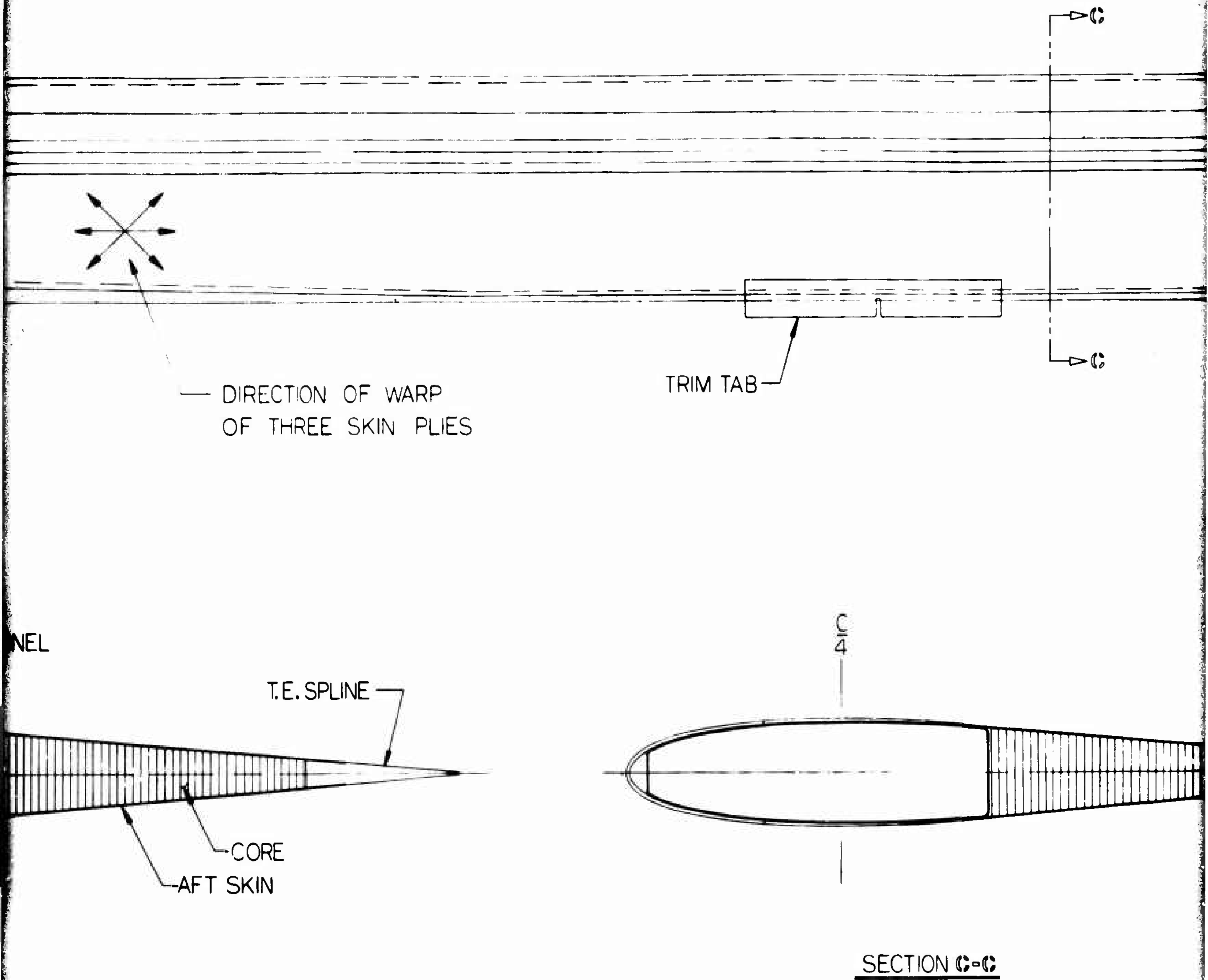
B
B
SKIN THICKNESS TRANSITION
DIRECTION OF WARP
OF THREE SKIN PLIES



STIFFENER
NOSE SKIN
BALLAST
C/4
AFT CHANNEL
T.E. SPLINE
CORE
AFT SKIN
SUPPORT CHANNEL

SECTION B-B

D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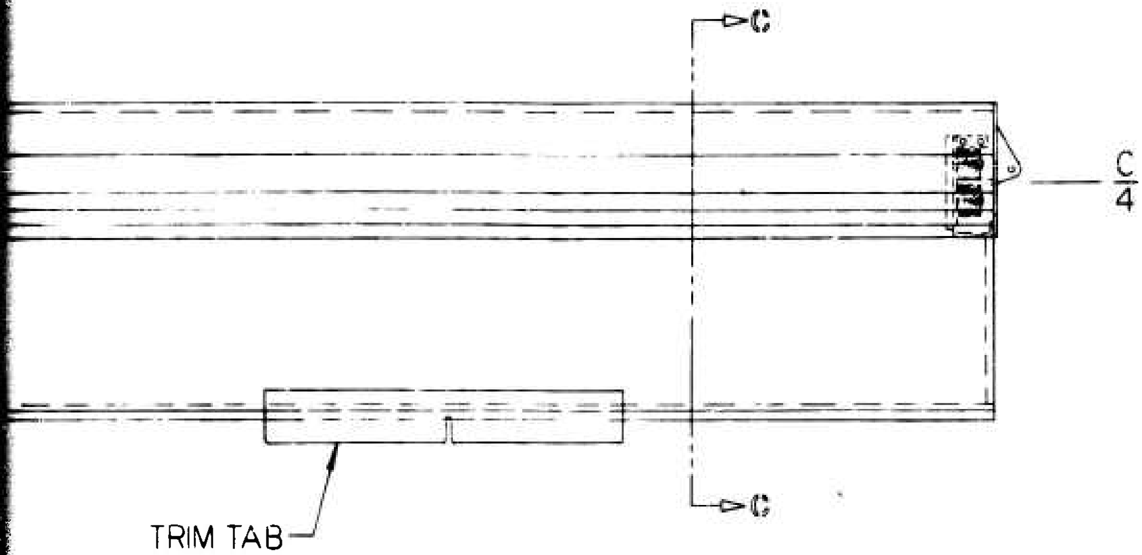
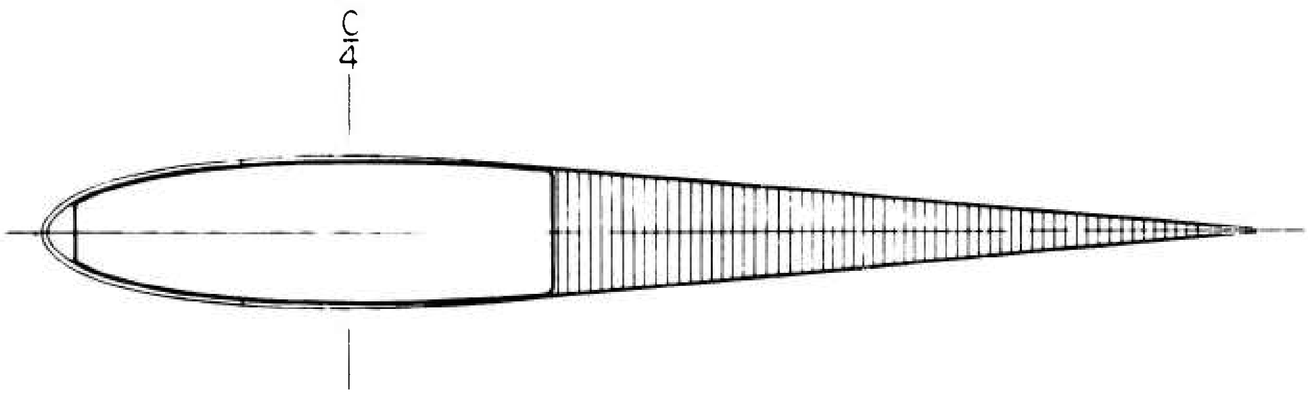
C
DIRECTION OF WARP
OF THREE SKIN PLIES
TRIM TAB
NEL
T.E. SPLINE
CORE
AFT SKIN
C/4
SECTION C-C

D

E





SECTION C-C

A

DESIGN CONSIDERATIONS

1. AIRFOIL SECTION MODIFIED TO PROVIDE STRAIGHT-SIDED AFT SECTION.
2. CONSTANT-SECTION EXTRUDED SPAR.
3. INTERNAL IN-PLANE SHEAR MEMBER.
4. NONSTRUCTURAL EXTERNAL AFT SKINS.
5. UTILIZES EXISTING RETENTION.
6. LIMITED VARIATION IN SECTION PROPERTIES.
7. LIGHTWEIGHT NOMEX HONEYCOMB CORES WITH STRAIGHT SIDES FOR SIMPLE CARVING.

FABRICATION

1. PROCESSING SIMILAR TO PRESENT UH-1 BLADE.

RELIABILITY AND MAINTAINABILITY

1. THICK LEADING EDGE TOLERANT OF ABRASIVE DAMAGE.
2. LEADING EDGE READILY BLENDED TO REMOVE DAMAGE.
3. AFT STRUCTURE PROTECTED FROM EXTERNAL DAMAGE.
4. AFT SKINS REPAIRABLE IN FIELD.

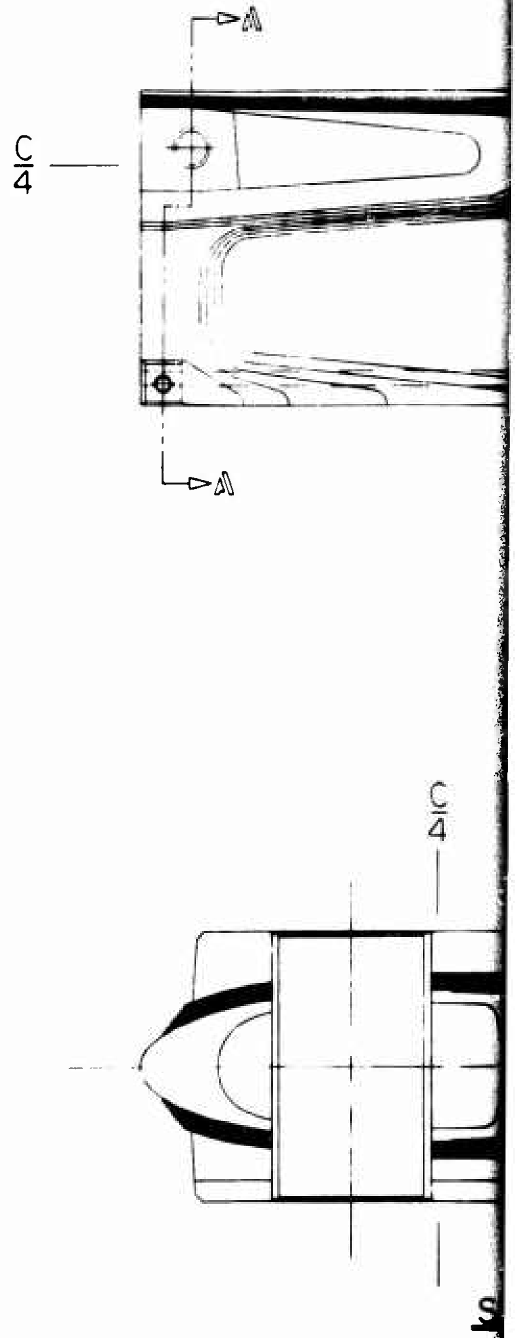


Figure 4. Design 3, Expendable Rotor Blade, Buried Chord Plane Shear Web.

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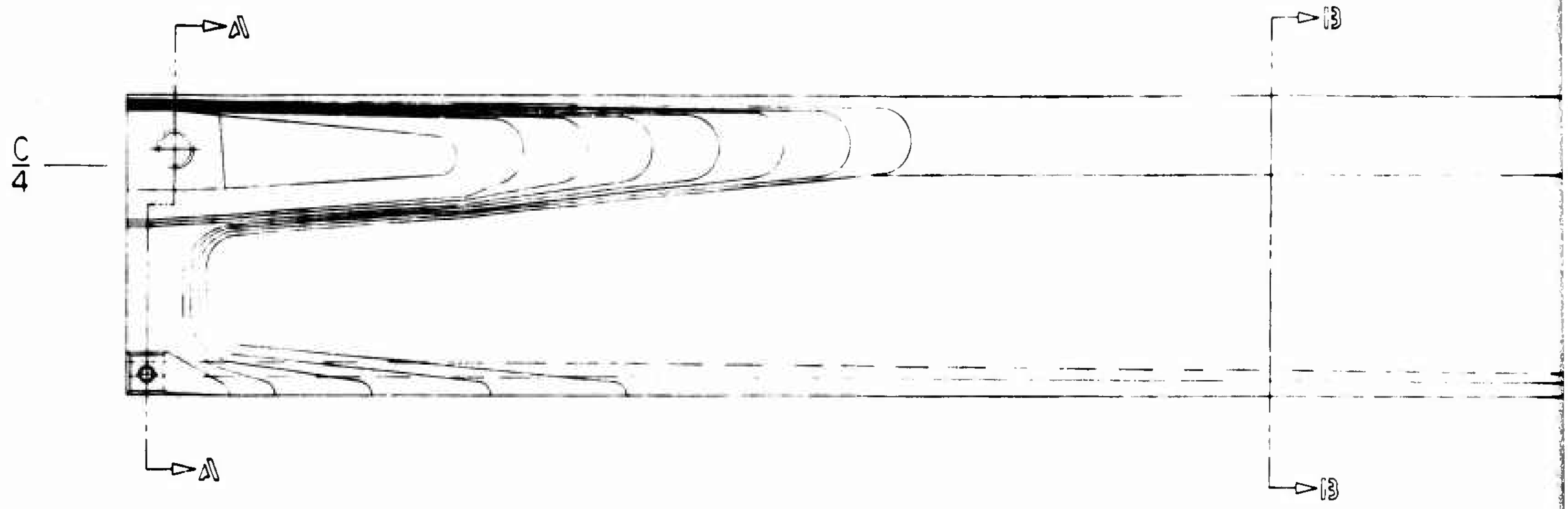

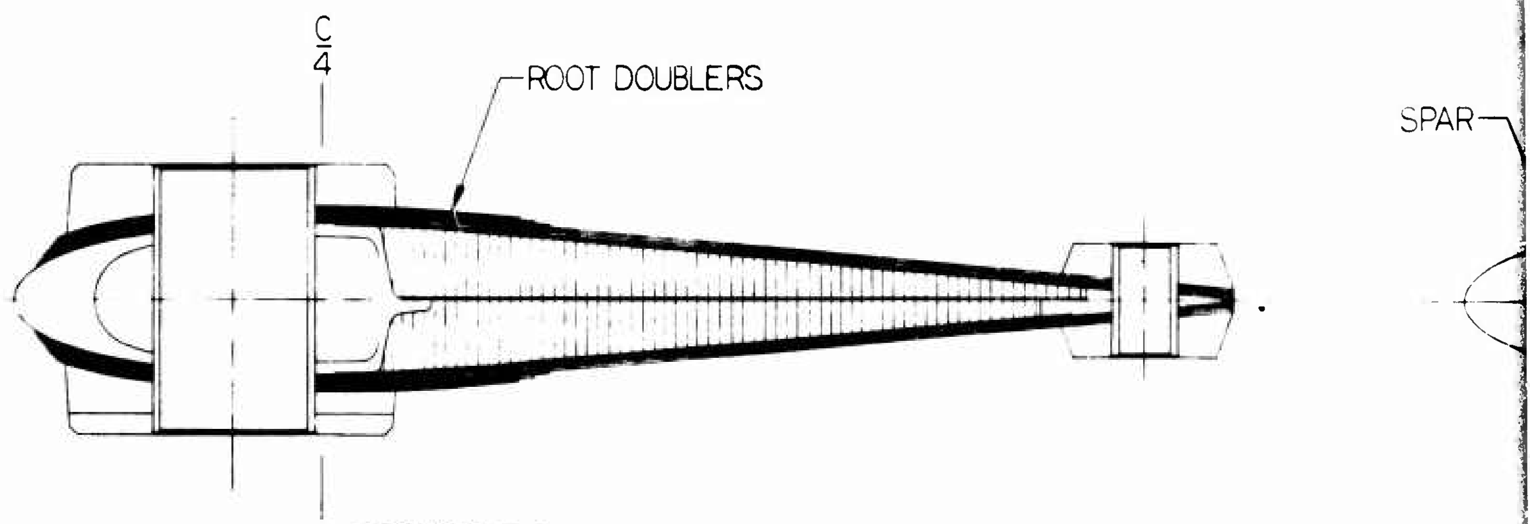

SECTION A-A

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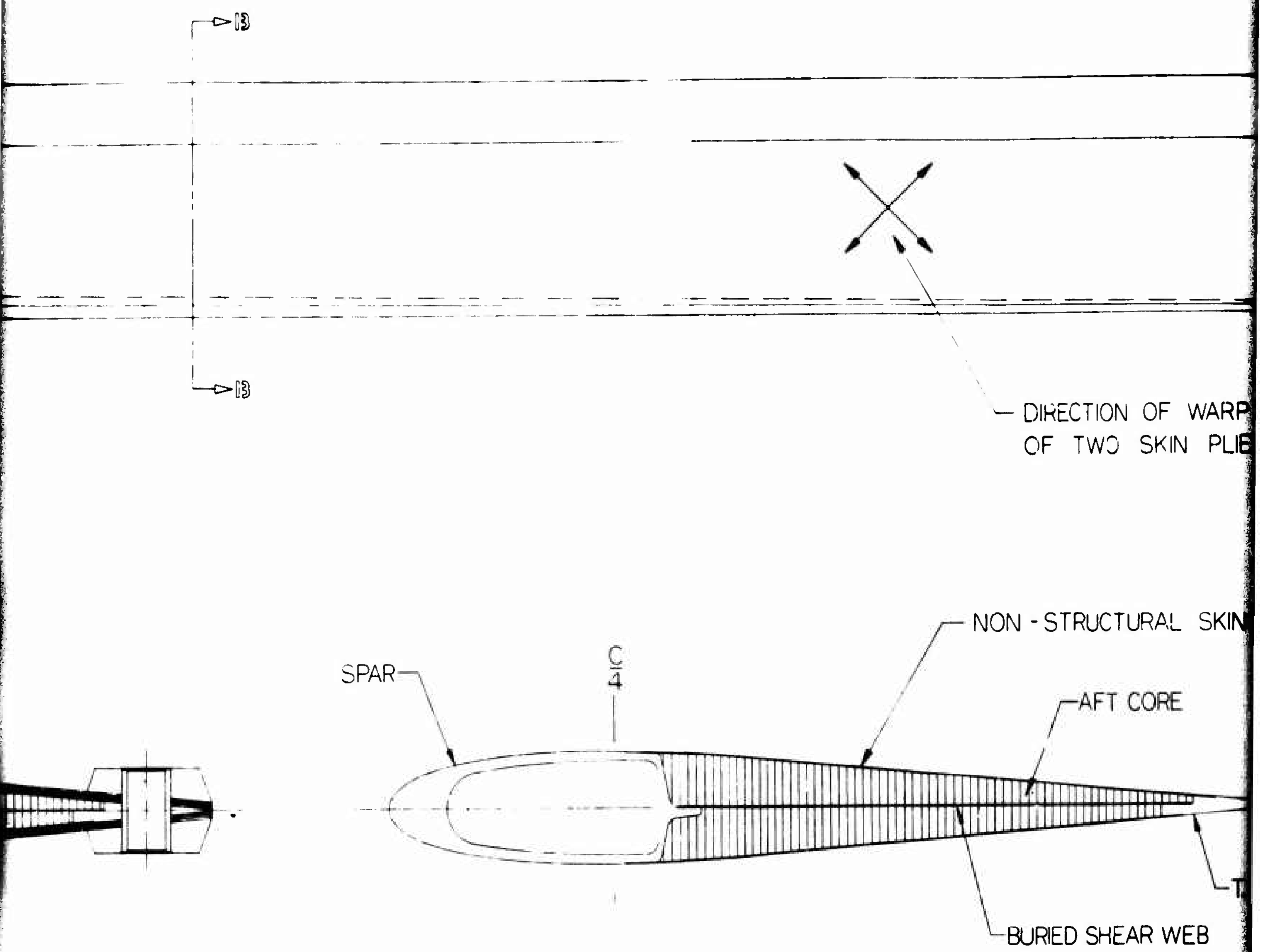
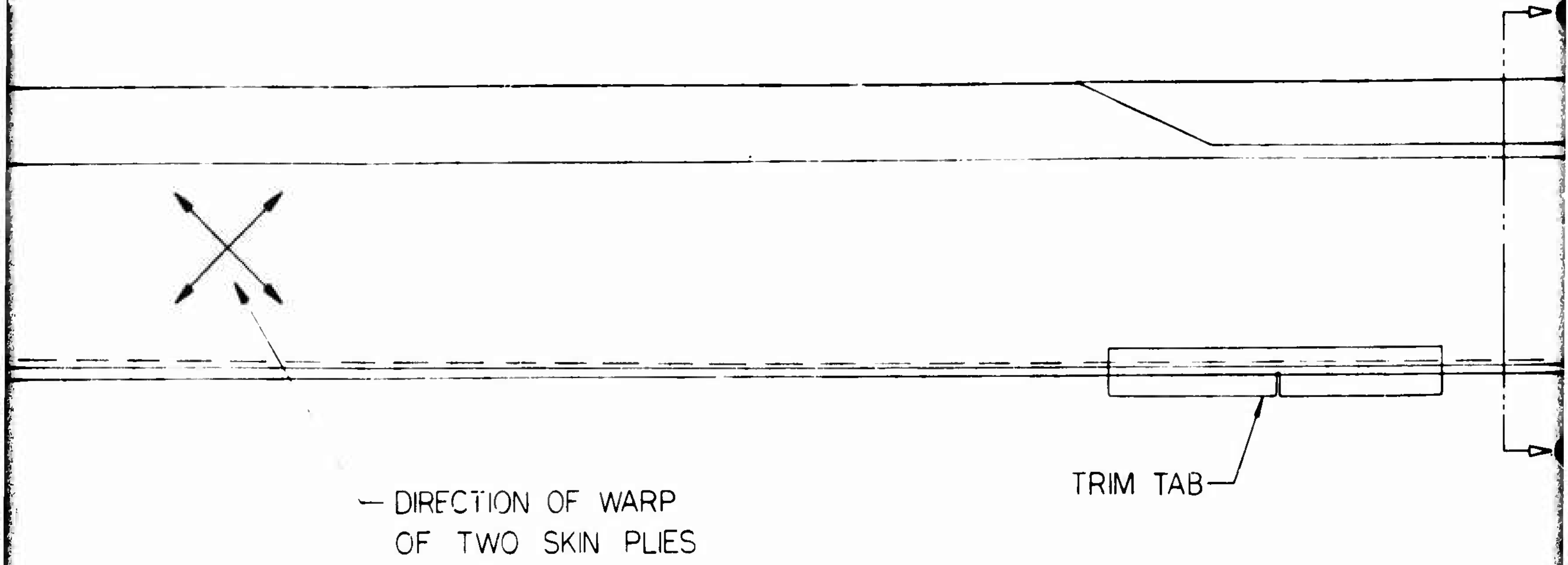
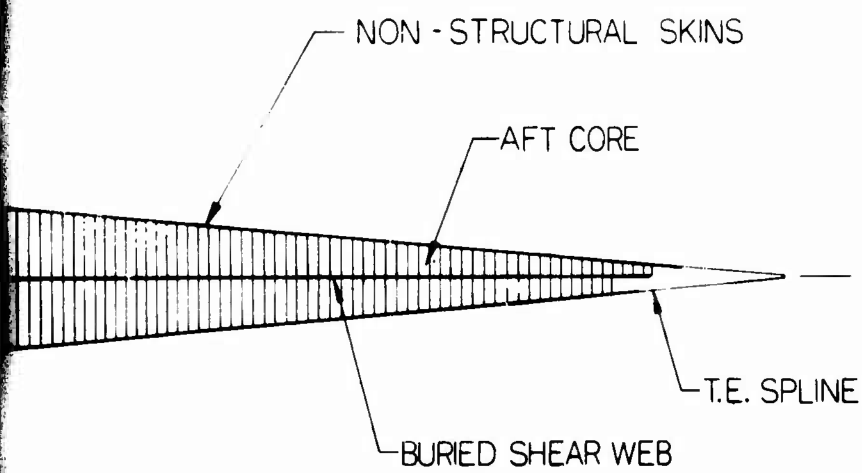

B
B
DIRECTION OF WARP
OF TWO SKIN PLIE
NON - STRUCTURAL SKIN
SPAR
C/4
AFT CORE
BURIED SHEAR WEB

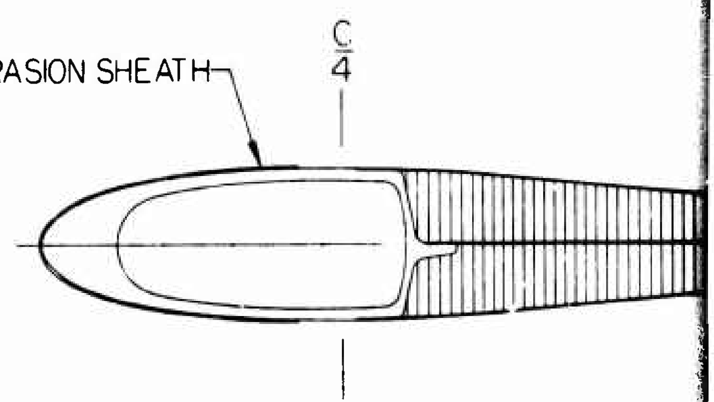
SECTION B-B

D





N B-B



SECTION C-C

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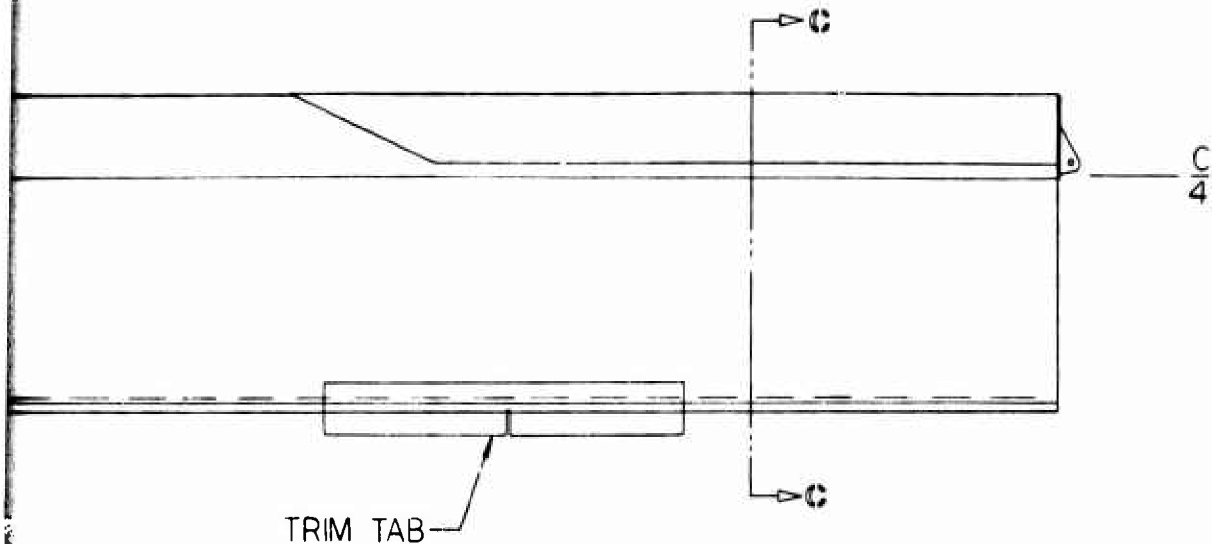
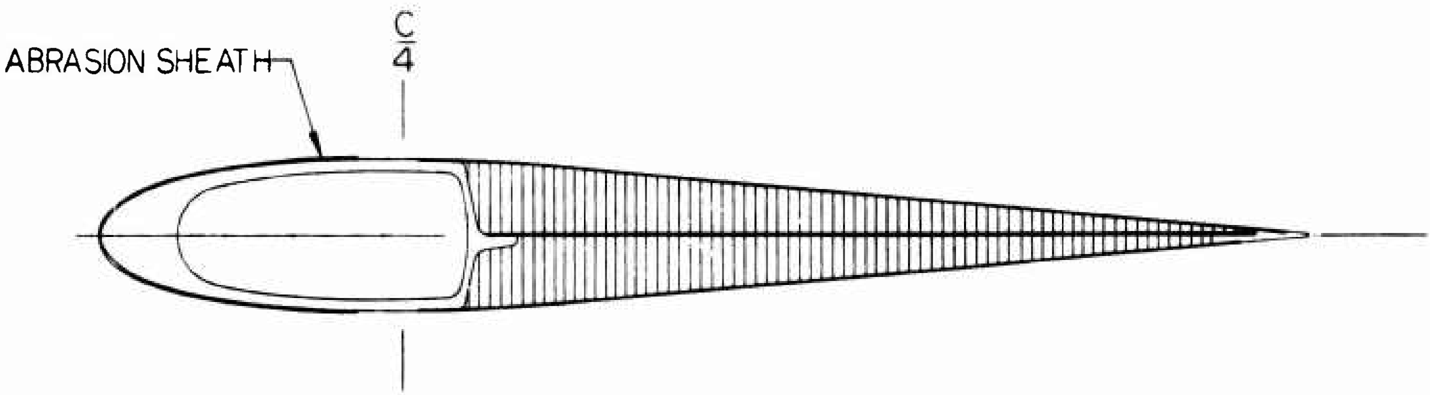
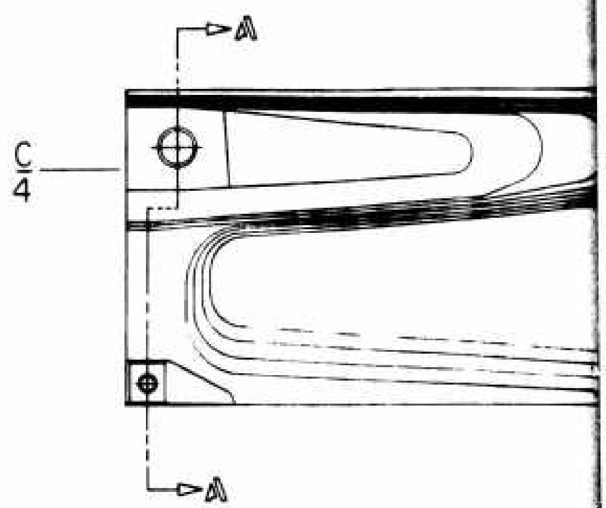




SECTION C-C

A



DESIGN CONSIDERATIONS

1. BASIC SECTION ASSEMBLED FROM TWO EXTRUSIONS.
2. UTILIZES EXISTING RETENTION
3. NO MACHINING REQUIRED OF EXTRUDED SPAR.
4. ROOT DOUBLER PLANFORM EXTENDED FOR IN-PLANE STIFFNESS.
5. SECTION PROPERTIES NOT EASILY VARIED ALONG SPAR.

FABRICATION

1. BENDING OPERATIONS SIMPLER THAN PRESENT UH-1 BLADE.
2. EXTRUDED AFT SKIN CHEMICALLY MILLED TO THICKNESS.
3. PROCESSING OF ROOT REINFORCEMENT SIMILAR TO PRESENT BLADE.

RELIABILITY AND MAINTAINABILITY

1. THICK LEADING EDGE TOLERANT OF ABRASION DAMAGE.
2. LEADING EDGE READILY BLENDED TO REMOVE DAMAGE.
3. DAMAGED AFT SECTION CANNOT BE REPAIRED.

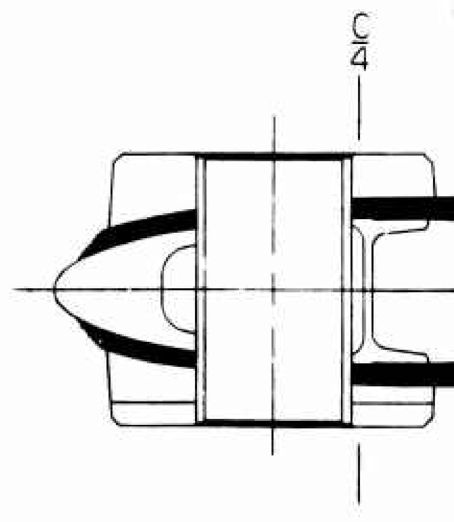


Figure 5. Design 4, Expendable Rotor Blade, Two Basic Extrusions.

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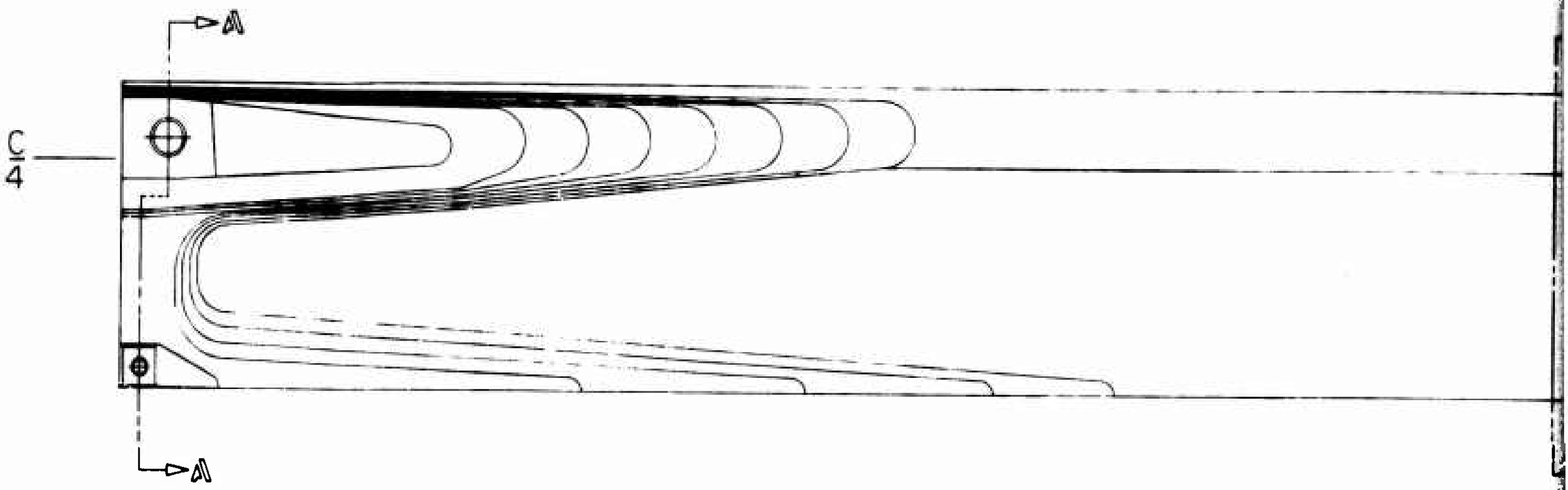

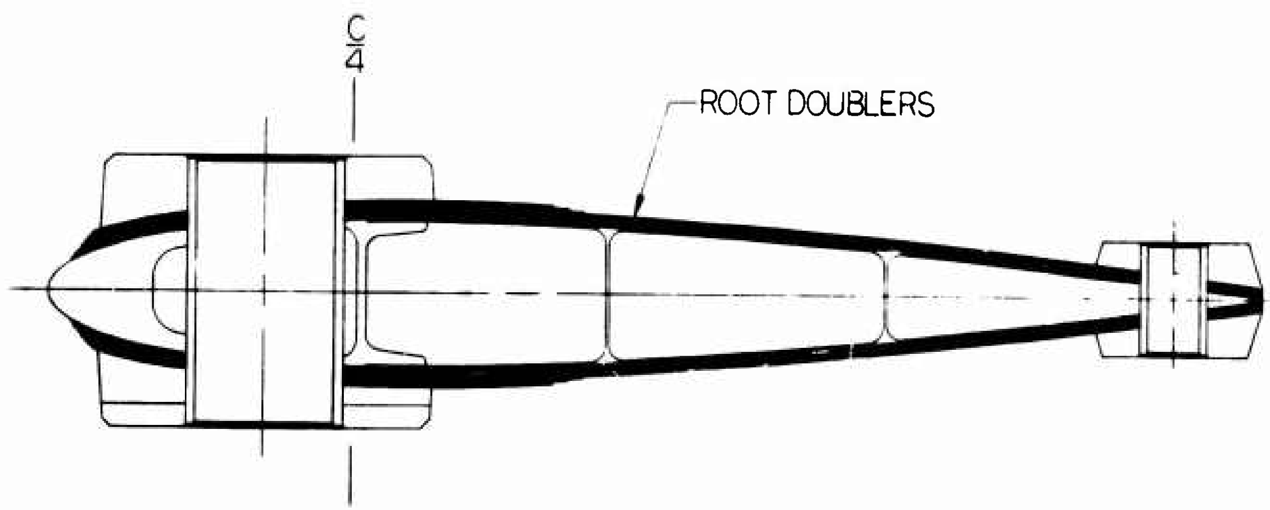

SECTION A-A

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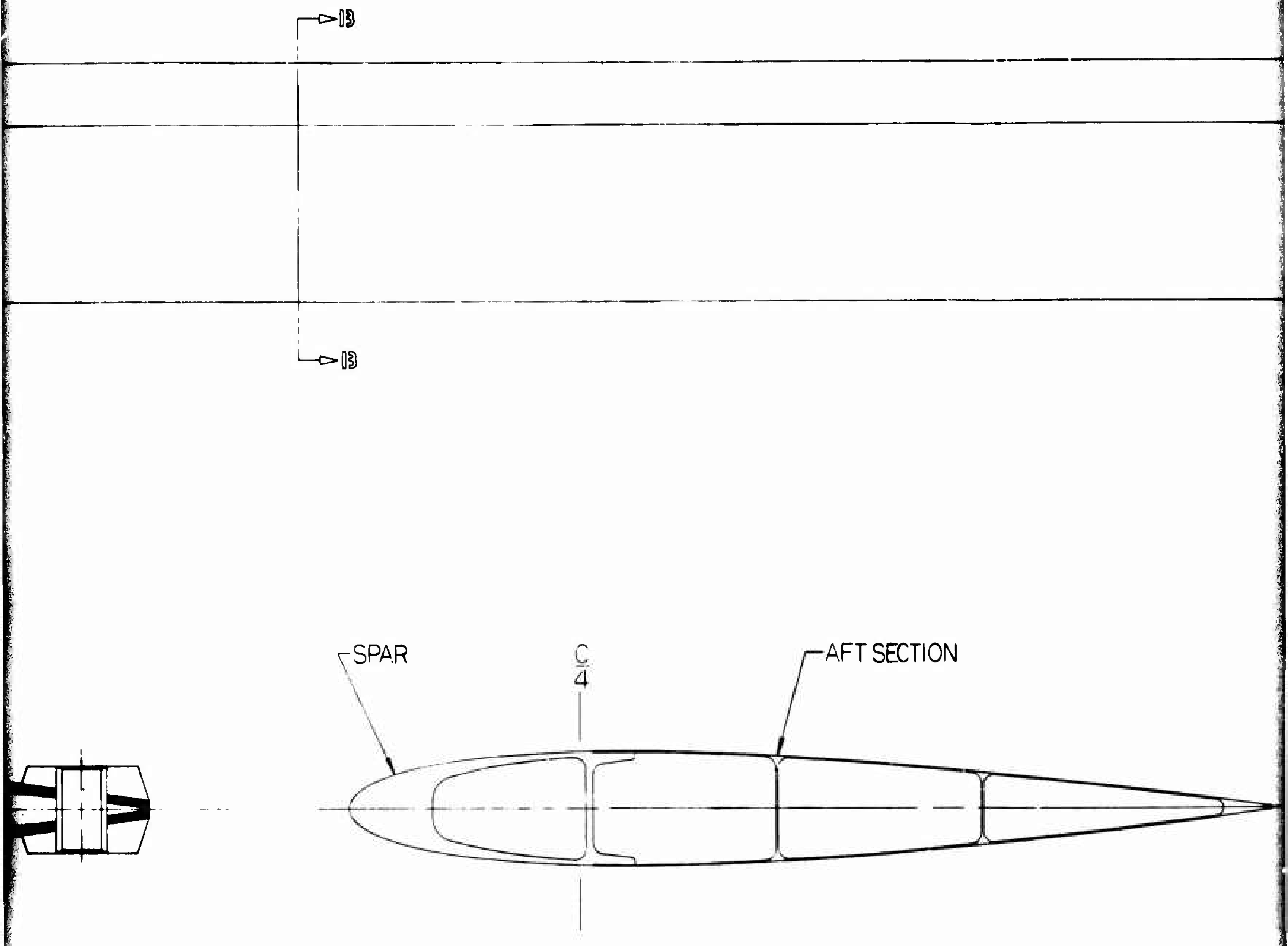
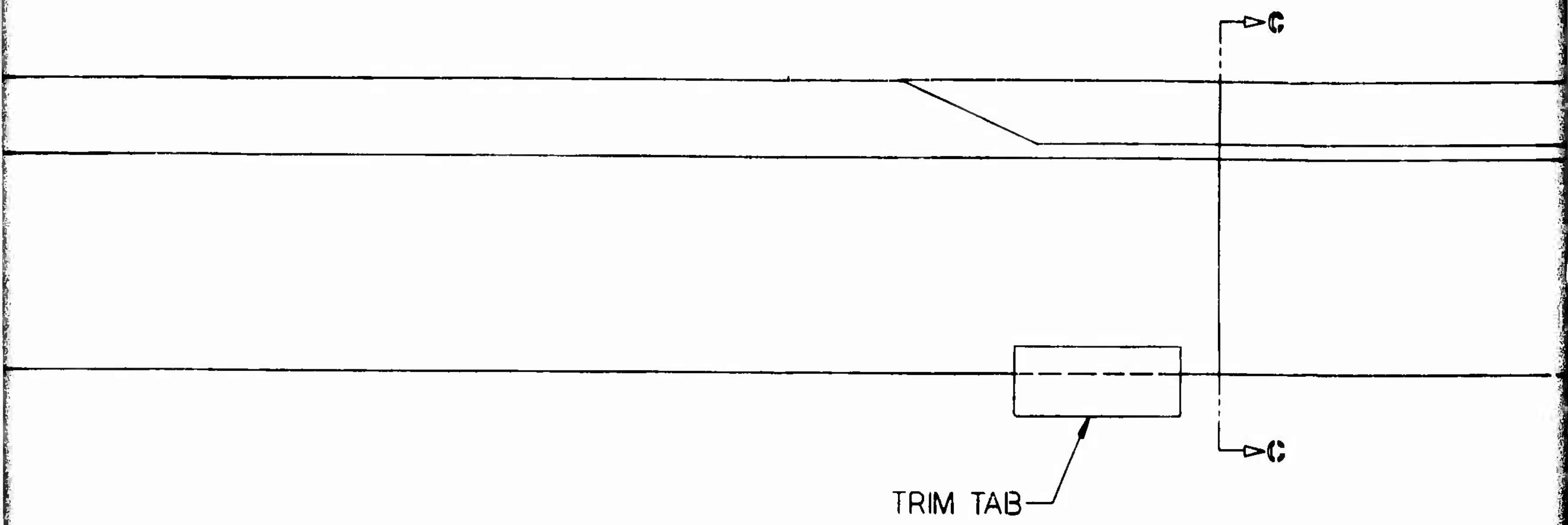
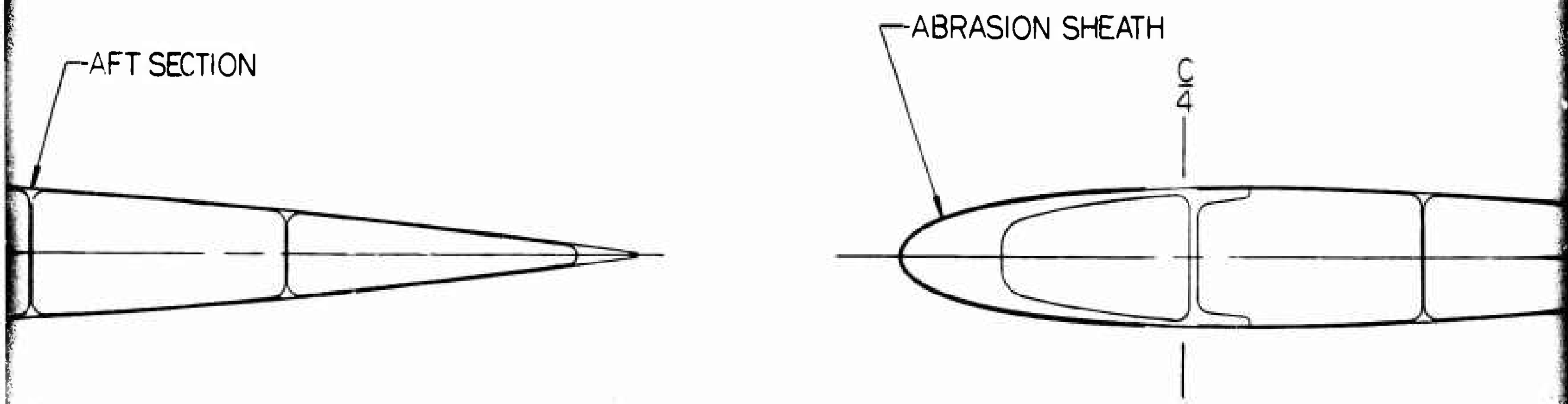


SECTION 13-13

D

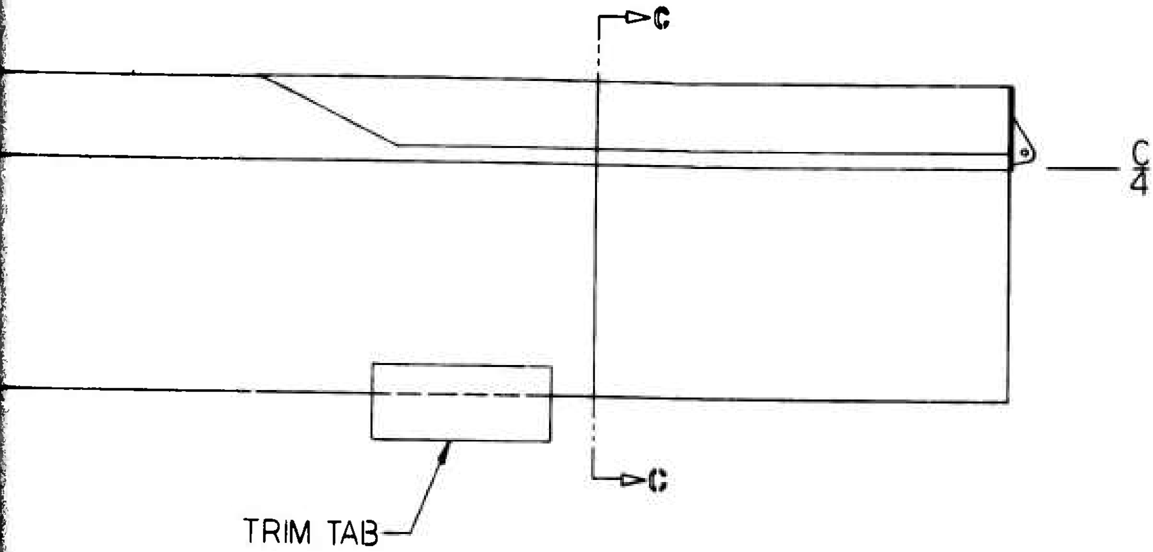


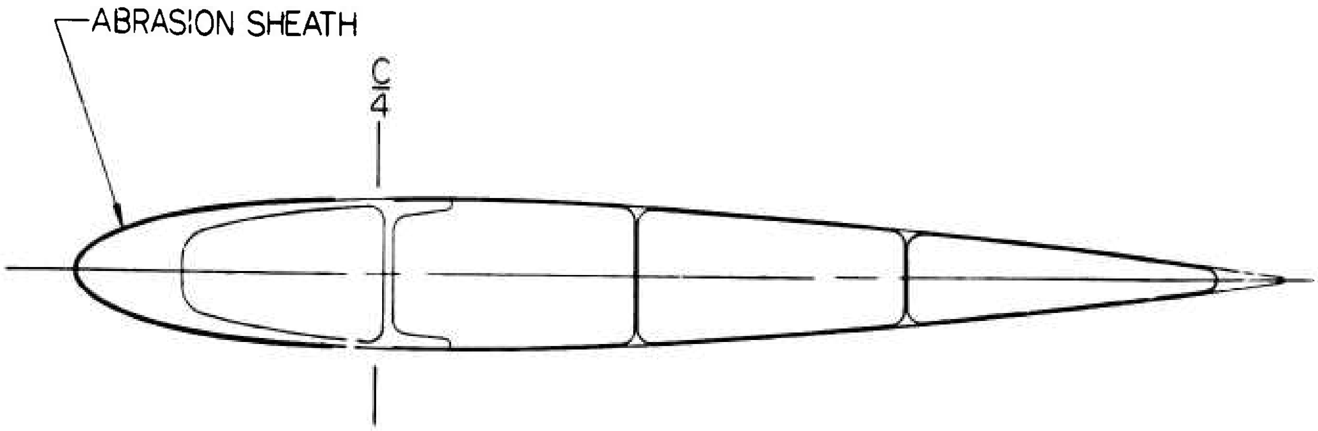


SECTION C-C

D

E





SECTION C-C

TABLE I. BLADE DESIGNS STUDIED

Configuration	Main Spar		Aft Section		
	Structure	Nose Ballast	Skins	Core	Spline
Design 1	Extruded Aluminum Alloy 6061-T6	Integral	Clad Aluminum Alloy Sheet 2024-T4	Aluminum Honeycomb	Extruded Aluminum Alloy 6061-T6
Design 2	Formed Stainless Steel Sheet AISI-301	Extruded or Drawn Stainless Steel AISI-301	Glass-Fiber-Reinforced Plastic 3-Ply	Polyamide Paper Honeycomb ("Nomex")	Unidirectional Glass-Fiber-Reinforced Plastic
Design 3	Extruded Aluminum Alloy 6061-T6	Integral	Glass-Fiber-Reinforced Plastic 2-Ply	"Nomex" Honeycomb with Al. Alloy Sheet Chord Plane Shear Web, 2024-T4	Extruded Aluminum Alloy 6061-T6
Design 4	Extruded Aluminum Alloy 6061-T6	Integral	Extruded Aluminum Alloy 6061-T6	Integral Vertical Webs	Integral

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For protection against abrasion and erosion, a cobalt alloy abrasion sheath, similar to that installed on the current blade, is provided over the outer 4 feet of leading edge. The root hardware and reinforcement are the same, except for the difference in contour, as those of the current UH-1D/H blade; the tip hardware and trim tab are identical to those of the current blade, but the trim tab is not riveted.

Design 2

This concept is illustrated in Figure 3. The basic blade consists of a spar constructed from two formed stainless steel sheet parts, bonded together with the airfoil shape completed by a glass-fiber-reinforced plastic afterbody. For section balance, a stainless steel ballast bar is bonded into the nose. Because the nose skin is a heavy stainless steel sheet, additional protection against abrasion and erosion is not required. To facilitate carving of the core, the modified airfoil section described in Design 1 is utilized.

The basic spar structure is a stainless steel box beam, in two parts adhesively bonded together. These two parts are the thick nose skin, formed to contour, and the channel-shaped shear web whose flanges fit inside the nose skin, closing the box. For balance, an extruded or drawn stainless steel ballast bar, supported by a stainless steel channel, is bonded into the nose. So that the almost flat underside of the box beam is not buckled in compression by the static droop bending moment, a partial-span channel-section stiffener is bonded between the upper and lower sides, at the root, extending beyond the root reinforcement doublers. To provide mass and stiffness taper corresponding to that of the current blade, the nose skin is tapered in plan, from wide at the root to narrow at mid-span, remaining constant from there to the tip, and the flanges of the nose ballast support channel are tapered in the reverse direction. To simplify manufacture, the nose ballast bar is not tapered.

The aft section is made up of a pair of glass-fiber-reinforced plastic skins, laid up basically from three plies, one of which has its warp parallel to the span and the other two $\pm 45^{\circ}$ from it. These skins are supported by a polyamide paper ("Nomex") honeycomb core, and the trailing edge is completed by a unidirectional glass-fiber plastic molded spline. The aft skins are locally thickened at their forward edges by additional plies, to match the thickness of the stainless steel nose skins; this added thickness is carried to the trailing edge in the region under the root doublers. The trailing edge spline is tapered to provide sufficient in-plane stiffness at the root, and to allow correct forward location of the section center of gravity at the tip. The location of the spar shear web is sufficiently far aft that the honeycomb core can be carved using purely straight cuts.

The root hardware and reinforcement are identical to those of the current blade, except for the slight change in contour. At the tip, adjustable balance weights and the forward tip cover are supported by a formed sheet-metal bracket, while the aft section is closed by a formed sheet-metal or molded plastic rib. The trim tab is longer, in the span direction, and narrower than the current trim tab, the better to distribute tab loads into the relatively light aft structure. The trim tab is split into two segments for ease of adjustment.

Design 3

The unique feature of this concept, which is shown in Figure 4, is the internal shear web providing the shear path between the trailing-edge spline and the main spar. By utilizing this internal structure, the skins can be relatively light, carrying loads induced only by their own mass and stiffness. The main spar is an aluminum extrusion with a heavy nose mass for integral balance, as in Design 1. An aft-projecting tab extruded integral with the aft wall of the spar provides the surface to which the chord-plane shear web is bonded. The trailing edge spline is also extruded aluminum alloy, and is machined along the forward face to provide tapered in-plane bending stiffness and chordwise balance. The forward face is machined with a step to accept the shear web.

The aft skins are formed from two plies of glass-reinforced plastic oriented $\pm 45^{\circ}$ from the span axis. The skins are supported by two cores of "Nomex" honeycomb, separated along the chord line by the internal shear web. To facilitate carving of these cores, the modified airfoil section described in Design 1 is utilized.

Except for the difference in contour, the root reinforcement is the same as that of the current blade. A formed sheet metal bracket supports the adjustable tip weights and forward tip cover, while a formed sheet metal or molded plastic tip rib closes the aft section. Because of the light plastic aft skins, the high-aspect-ratio segmented trim tab of Design 2 is used. For protection against abrasion and erosion, a cobalt alloy abrasion sheath is provided over the outer 4 feet of the leading edge, the same as that proposed for Design 1.

Design 4

This concept is illustrated in Figure 5. The basic blade is formed from two aluminum alloy extrusions, bonded together just aft of the quarter-chord. The root retention doublers and grip plates are common to the present blade, while the outboard 4 feet are protected by a cobalt alloy abrasion sheath similar to that installed on the current blade. Because there is no aft core, contour is not critical in manufacture, and the standard NACA 0012 airfoil section used on the current blade is retained to avoid even small changes in aerodynamic behavior.

The nose balance weight is extruded as an integral part of the spar, as in Designs 1 and 3. Section balance requires that the walls of the aft section be so thin that they are unachievable by extrusion, so that they must be reduced subsequently to the desired thickness. This additional operation is expensive and significantly increases the cost of the part.

Because the blade is constructed of extrusions, no taper is possible in structural or mass properties, so that the in-plane bending stiffness cannot be maintained as high at the root as that at the root of the current blade without creating weight and balance problems outboard. Therefore, in order to provide sufficient in-plane stiffness inboard, the aft fingers of the four doublers, top and bottom, which lie under the drag plates, are extended outboard beyond the forward tips. In all other respects, the root reinforcement is identical with that of the current blade.

The tip cover is similar to that of the current blade, and the cover and adjustable tip balance weights are supported by a formed sheet metal bracket, similar to the configuration of Design 2. The trim tab is identical to that of the current blade, except that it is bonded only, without rivets. The aft section is closed at the tip by a formed aluminum alloy rib riveted and bonded in place.

Although this particular concept showed promise of being the most economical because the basic blade consists of two parts only, the necessarily thin walls of the aft section make it prohibitively expensive, if not impossible, to manufacture. For weight and balance reasons, the aft section walls cannot be thicker than .025 inch, but the minimum extrudable thickness in this size of closed section is .156 inch, and the tolerance due to die wear and mandrel float would be greater than .020 inch. In consequence, the walls would have to be milled to the desired thickness after extrusion, and because of the broad tolerance band, the amount to be milled away would vary according to the local extruded thickness. The part cannot, therefore, be finished by any process, such as chemical milling, which removes a constant amount of material from all surfaces. Further complicating the problem is the impracticality of chemically milling the interior, which cannot be conveniently vented.

In the light of the above considerations, no further investigation of Design 4 was undertaken after the technical analysis was completed and a preliminary manufacturing study disclosed the wall thickness problem described above. Further consideration of Design 4 was, therefore, dropped from this study.

INTERCHANGEABILITY

An essential characteristic of an expendable blade is that it should be possible to remove any blade from the aircraft and replace it with a new one, and achieve (with a minimum of difficulty) acceptable balance and track compatibility with the other blade (or with all the other blades of a multi-blade rotor). This compatibility is in two phases, the first of which is mass balance interchangeability, while the second is equality of aerodynamic forces and moments.

To accomplish mass balance interchangeability, a procedure is suggested here which has been successfully followed on several production series of helicopter rotor blades. This procedure has been demonstrated to reduce out-of-balance forces, due to manufacturing weight variations, to below perceptible levels, and to eliminate the need for balance weight adjustment after the blades are installed on a rotor. Two essential parameters, the spanwise mass moment and the chordwise dynamic mass axis (the span-weighted chordwise center of gravity), are controlled during manufacture by this procedure.

The balancing procedure is performed in three stages: first, the component parts are selected by weight, prior to assembly, so that the range of adjustment is not exceeded; second, a preliminary calculation is performed to determine balance weight requirements; and third, the blade is physically balanced against a master to bring the final balance parameters within the accuracy required. This last step is limited to spanwise moment balance, because the dynamic axis cannot be physically determined on a static fixture.

To allow the final, physical balance step, adjustable weights are installed in the tip in two locations equidistant, fore and aft, from the desired dynamic axis. (A possible installation is shown in Figure 3.) Thus, by making equal changes to both stacks of adjustable weights from the requirement determined by calculation, the calculated dynamic axis will be undisturbed. It can be shown that even for the grossest errors that can be introduced during the selection stage, the physical correction of the spanwise moment will also correct the dynamic axis to within .010 inch of nominal. This variation is insignificantly small in comparison to contour and twist variations.

Controlling the dynamic axis, where each element of mass is considered to have an effect proportional to the centrifugal force acting on it, is a much more effective method of achieving mass balance interchangeability than by controlling the static center of gravity position. This is true even when the limits of accuracy are those resulting from a series of calculations. The effect is analogous to controlling the moment about the center of rotation rather than the radius to the center of gravity. The method of selecting components before assembly, however, ensures as a by-product that the chordwise location of the static center of gravity varies very little from blade to blade.

Under this procedure, the total weight will vary from blade to blade due to manufacturing tolerance, within the limits prescribed by the tip balance adjustment and the component selection procedure. The spanwise moment and product of inertia, respectively, about the center of rotation will each be identical for all blades, but the moment of inertia may vary slightly. Equality of spanwise moments will ensure that all blades will fly to the same flapping angles if they all have the same lift distribution, while equality of dynamic axes (the quotients of products of inertia divided by spanwise moments) will ensure that the twisting moments due to centrifugal force and flapping inertia will be equalized between blades. The latter condition eliminates any rotor frequency load variation in the cyclic control system due to differences in blade pitching moments, and minimizes inequalities in lift distribution due to differences in torsional deflection.

The component weighing and selection can be accomplished as part of the inspection procedure, while the physical balancing is simplified by correcting the moment about one axis only. This method of dynamic balancing, therefore, adds nothing to the cost burden on the blade.

Aerodynamic equalization can be accomplished by any standard tracking procedure, either on the aircraft or on a tower, by adjusting the trim tab to compensate for variations in contour and the pitch link to compensate for variations in twist. Since dynamic balancing will have been accomplished previously, there will be no necessity to adjust tip weights during tracking. The usual sweeps through the pitch range and through the speed range will be all that is required.

DETAIL DESIGN ANALYSIS

The design concepts studied for the expendable main rotor blade were analyzed for their structural and dynamic characteristics, to determine their compatibility with the UH-1D/H airframe and missions. Natural frequencies, flight bending moments, and stress levels were determined. To compare survivability rates, an analysis of failure modes and effects was performed for the current blade and for the three configurations showing the most promise of the four in this study. A previous study (Ref. 1) showed that root designs other than a built-up reinforcement, similar to that of the current UH-1D/H main rotor blade, offer little if any cost advantage. Consequently, the decision was made to use the built-up laminated root design of the current blade, and the basic blade configurations studied are all compatible with this root. The detail design analyses are concerned, therefore, with the dynamic and structural properties of the basic blade cross section, and the assumption is made that the structural characteristics of the roots of the four blade concepts studied herein are equal to those of the current blade root.

SECTION PROPERTIES

The basic blade configurations, illustrated in Figures 2 through 5, were all designed to have section properties (weight distribution, center-of-gravity location, structural neutral axis, and flapwise and in-plane bending stiffnesses) as close as possible to those of the current UH-1H main rotor blade. The differences in dynamic and structural characteristics between the study concepts and the current blade were thus minimized.

The contractor's computer program for computation of section properties was used, after first using the same program for the current blade to provide a valid basis for comparison. The section properties computed for the current blade are plotted as broken lines on each of the figures, for direct comparison.

Figures 6 through 10 present, respectively, the section weight distribution, center of gravity, structural neutral axis, and flapwise and in-plane bending stiffnesses of Design 1. Figures 11 through 15 present the same properties of Design 2, Figures 16 through 20 those of Design 3, and Figures 21 through 25 those of Design 4.

For each design concept, the root reinforcement was assumed to have properties similar to those of the current blade, and this assumption is reflected in the curves, at the inboard end of each figure. For Designs 1, 3, and 4, two sets of figures are plotted. These figures differ outboard of Station 240.0, where the solid line indicates the change due to the addition of the abrasion sheath, and the chain-dotted line represents the simple, unprotected basic blade.

Inboard section properties were computed at Station 82.0, immediately outboard of the root doublers, and Station 210.0 was used for the outboard reference section, beyond which the blade is essentially constant. For Design 2, the section properties were also obtained at Station 160.0, the end of the nose skin taper, and for Designs 1, 3, and 4, the abrasion sheath was incorporated at Station 245.0. Inboard of Station 82.0, the curves were faired into those for the current UH-1H blade.

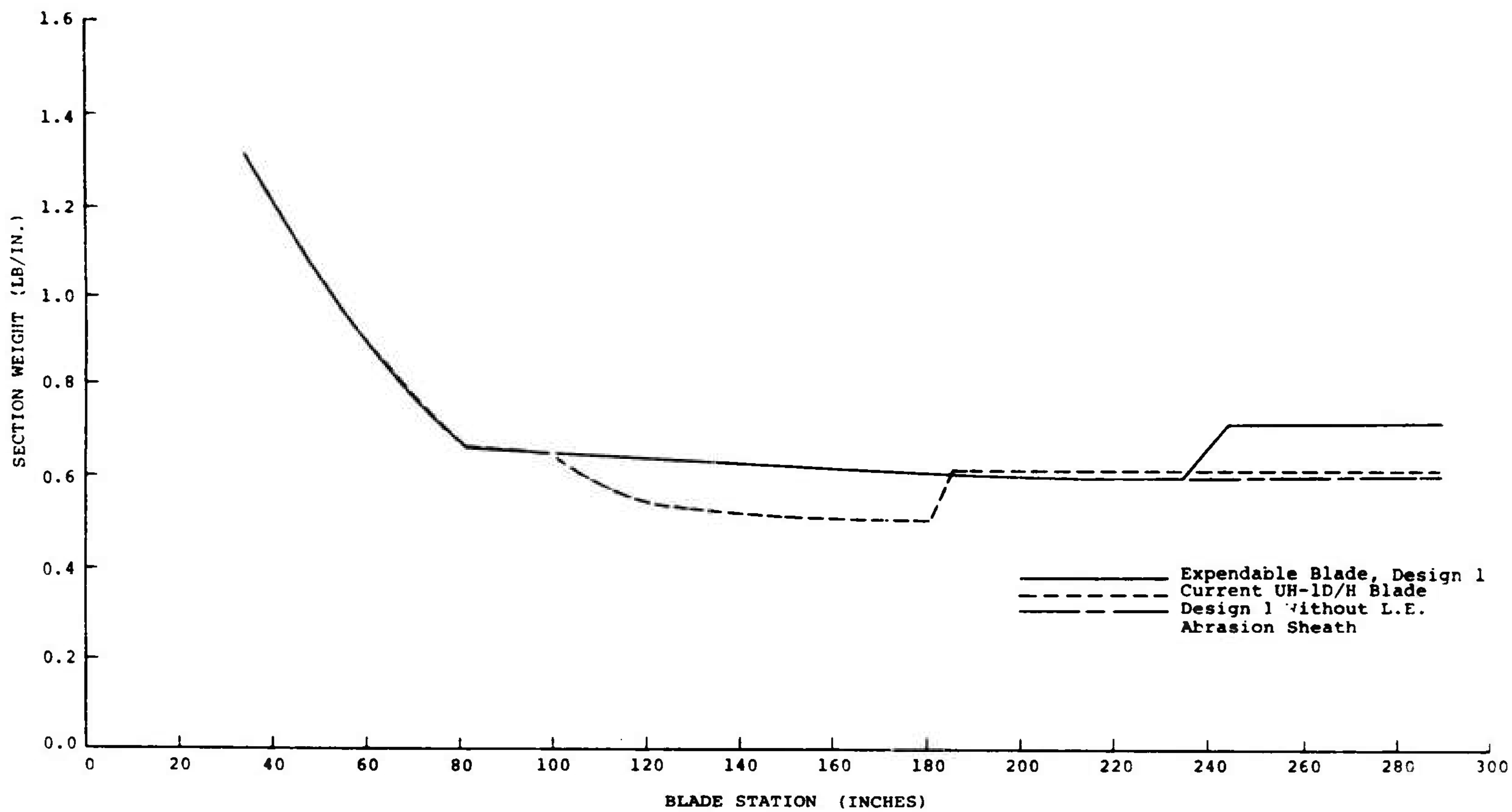

Figure 6. Weight Distribution, Design 1.

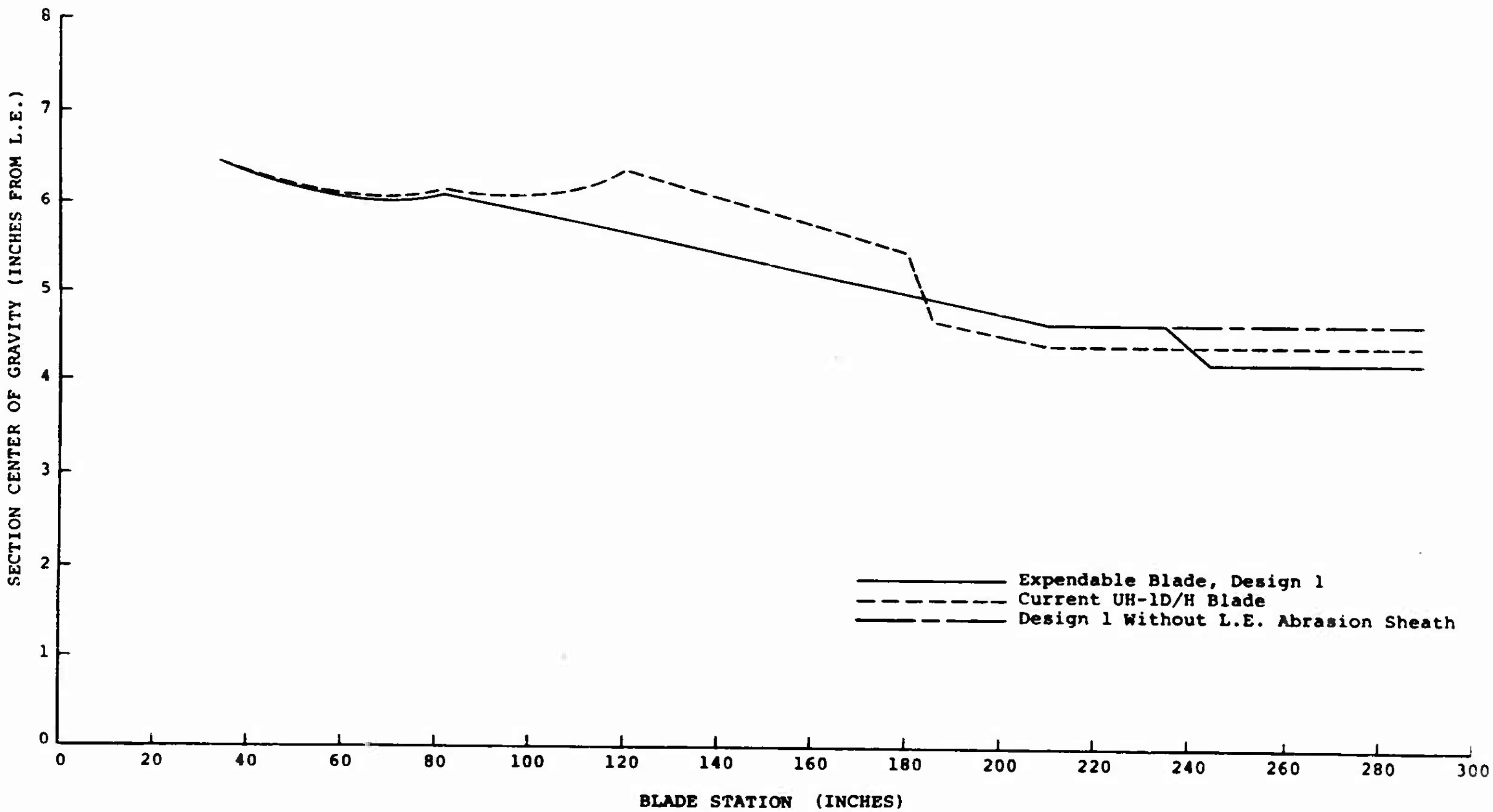

Figure 7. Center of Gravity, Design 1.

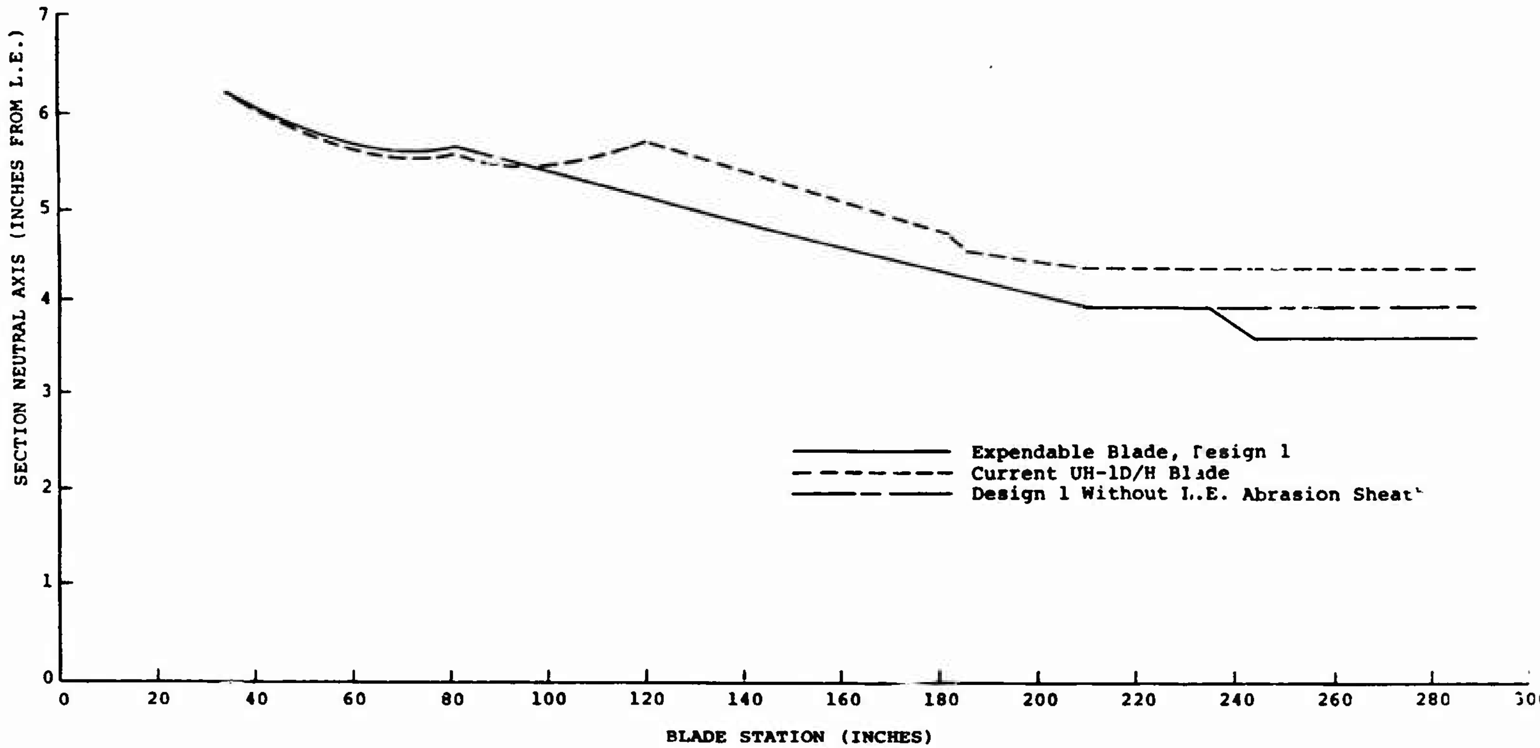

Figure 8. Neutral Axis, Design 1.

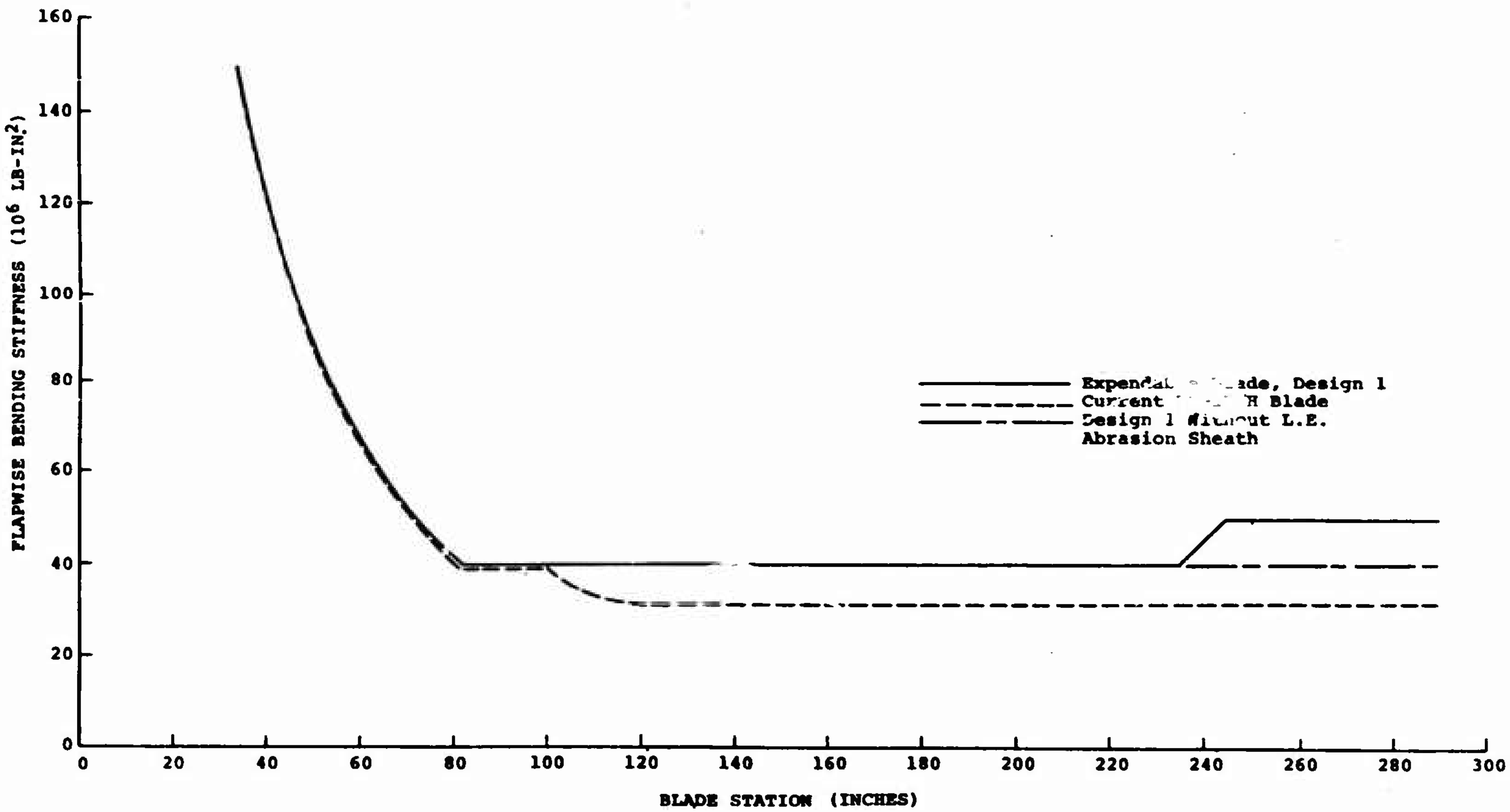

Figure 9. Flapwise Bending Stiffness, Design 1.

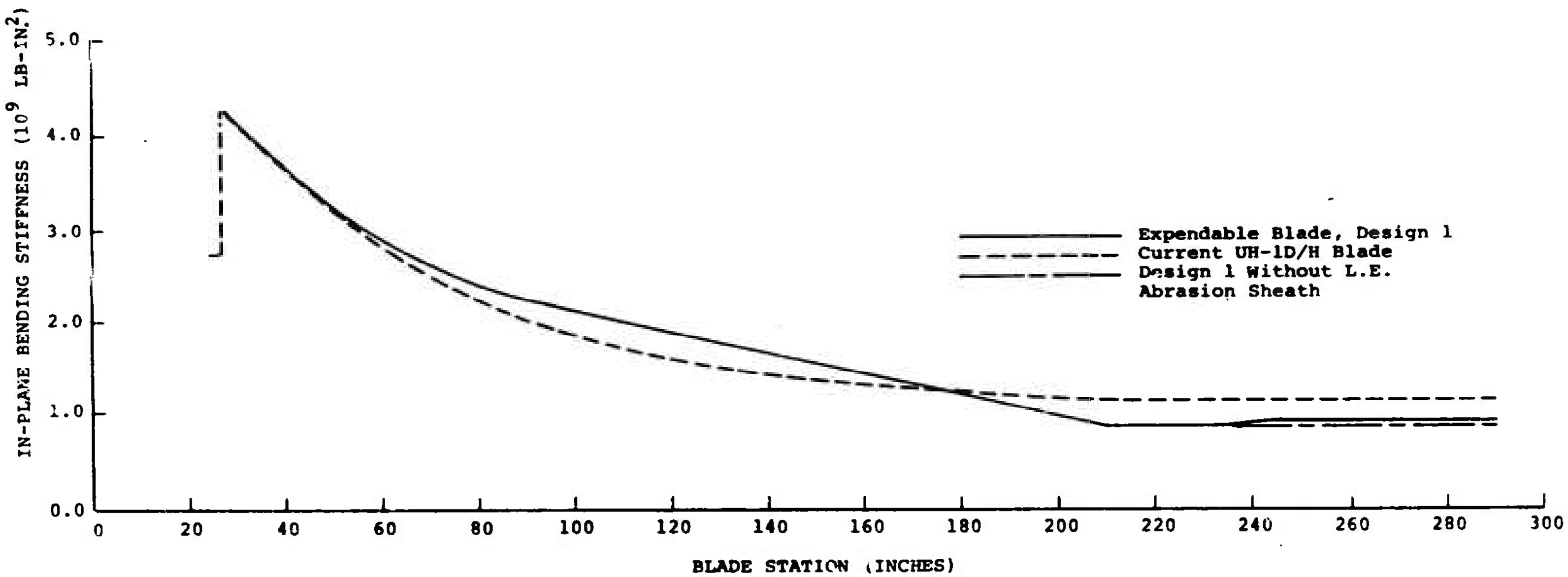

Figure 10. In-Plane Bending Stiffness, Design 1.

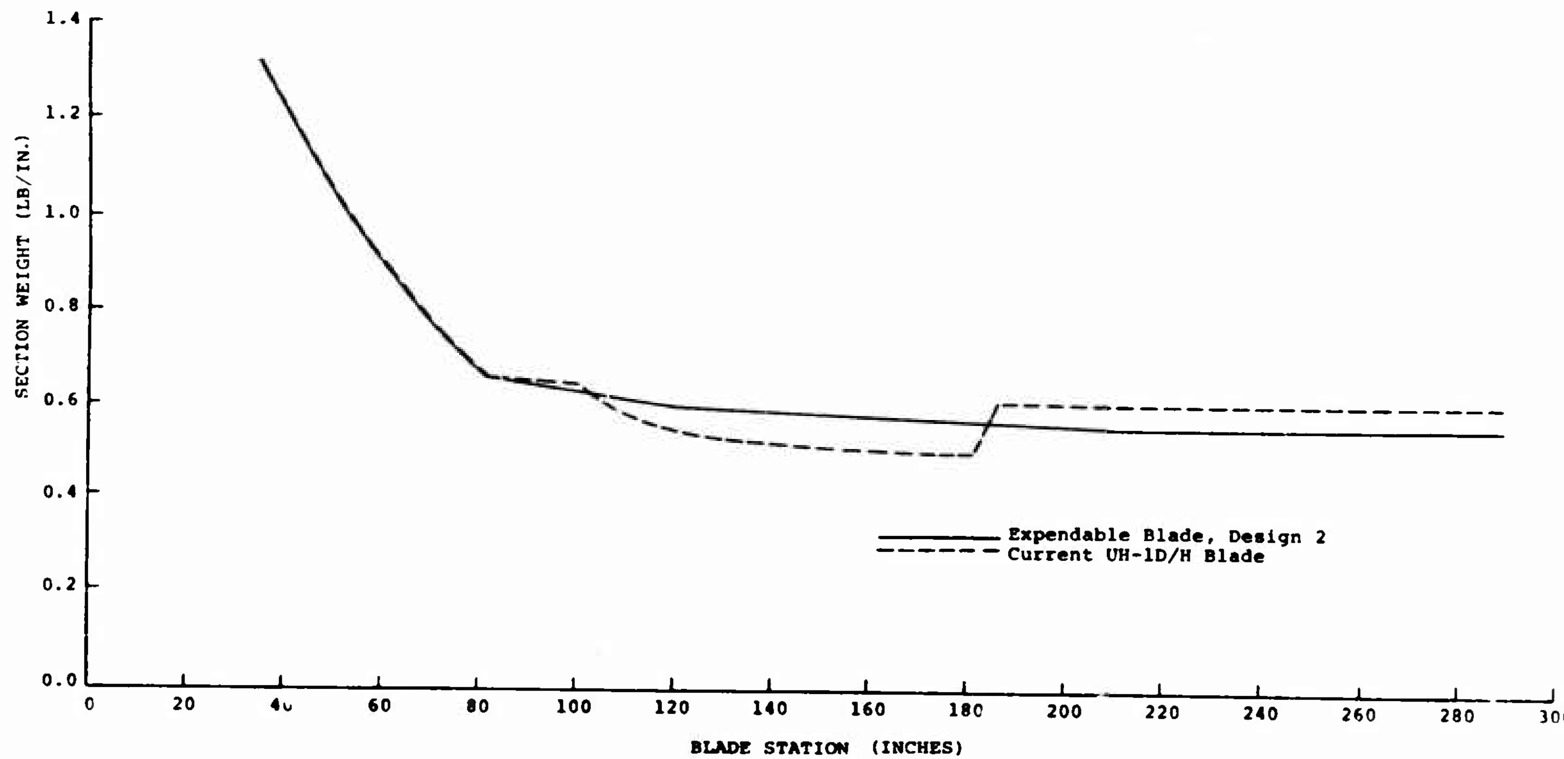

Figure 11. Weight Distribution, Design 2.

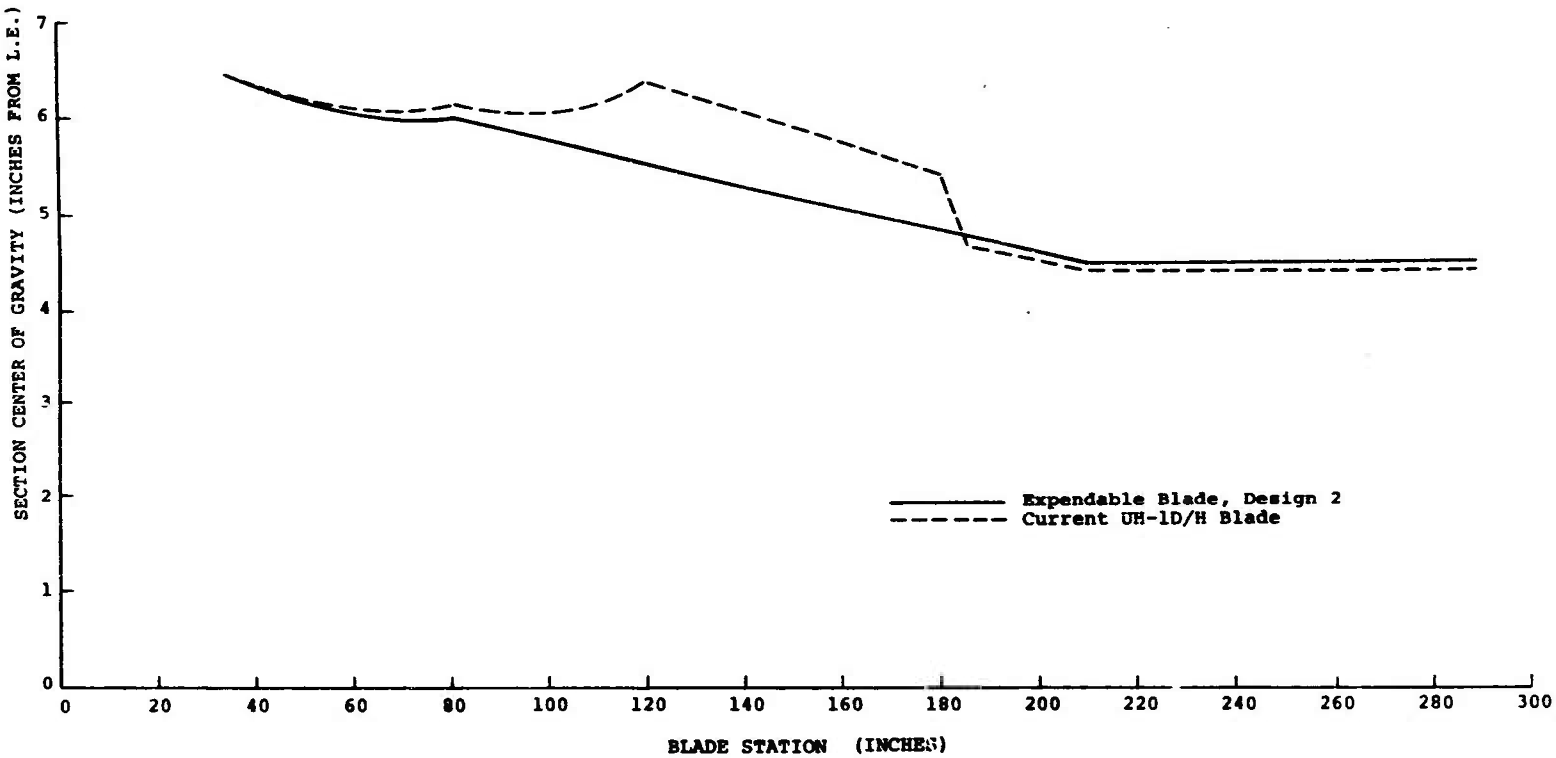

Figure 12. Center of Gravity, Design 2.

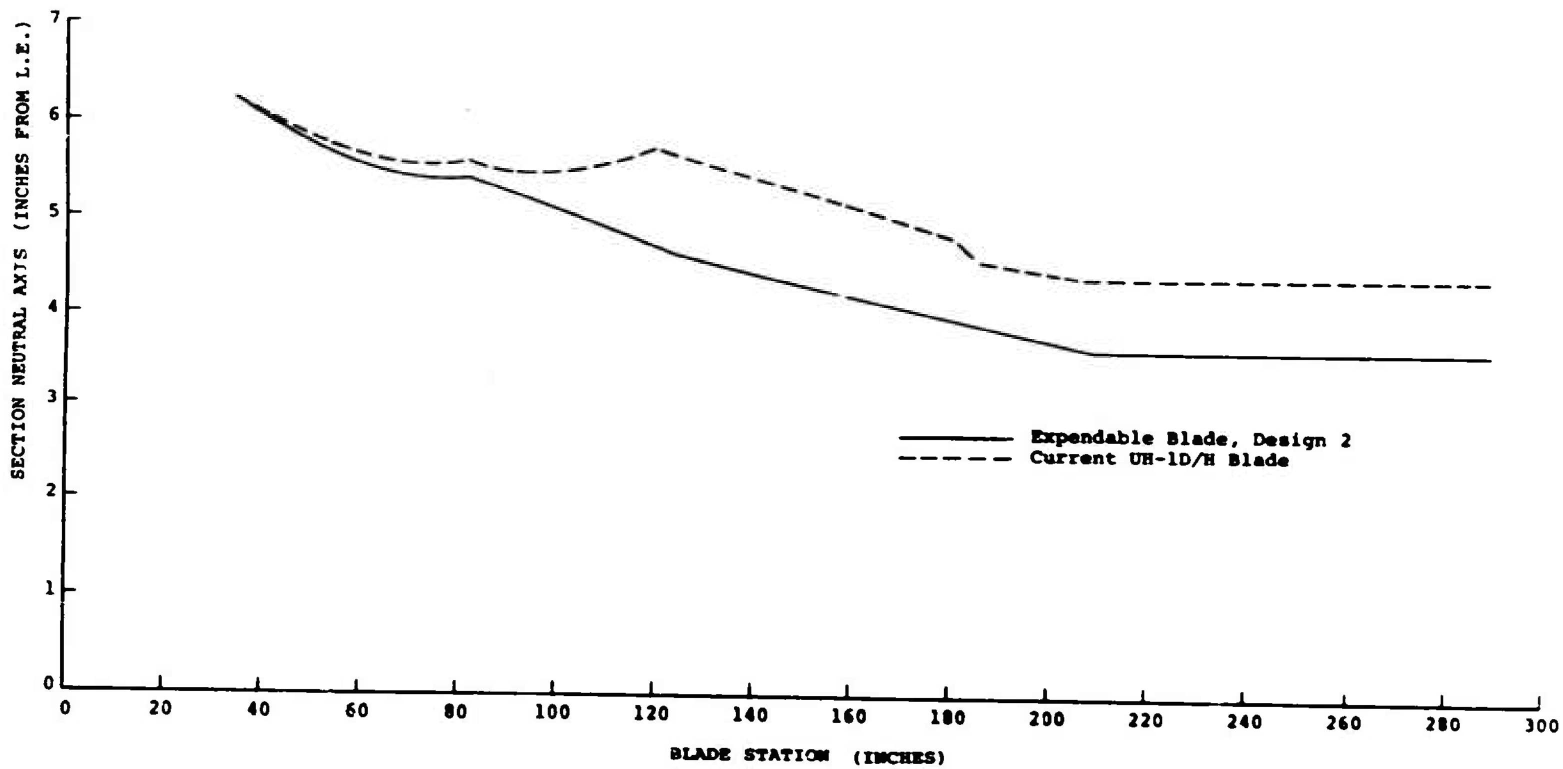

Figure 13. Neutral Axis, Design 2.

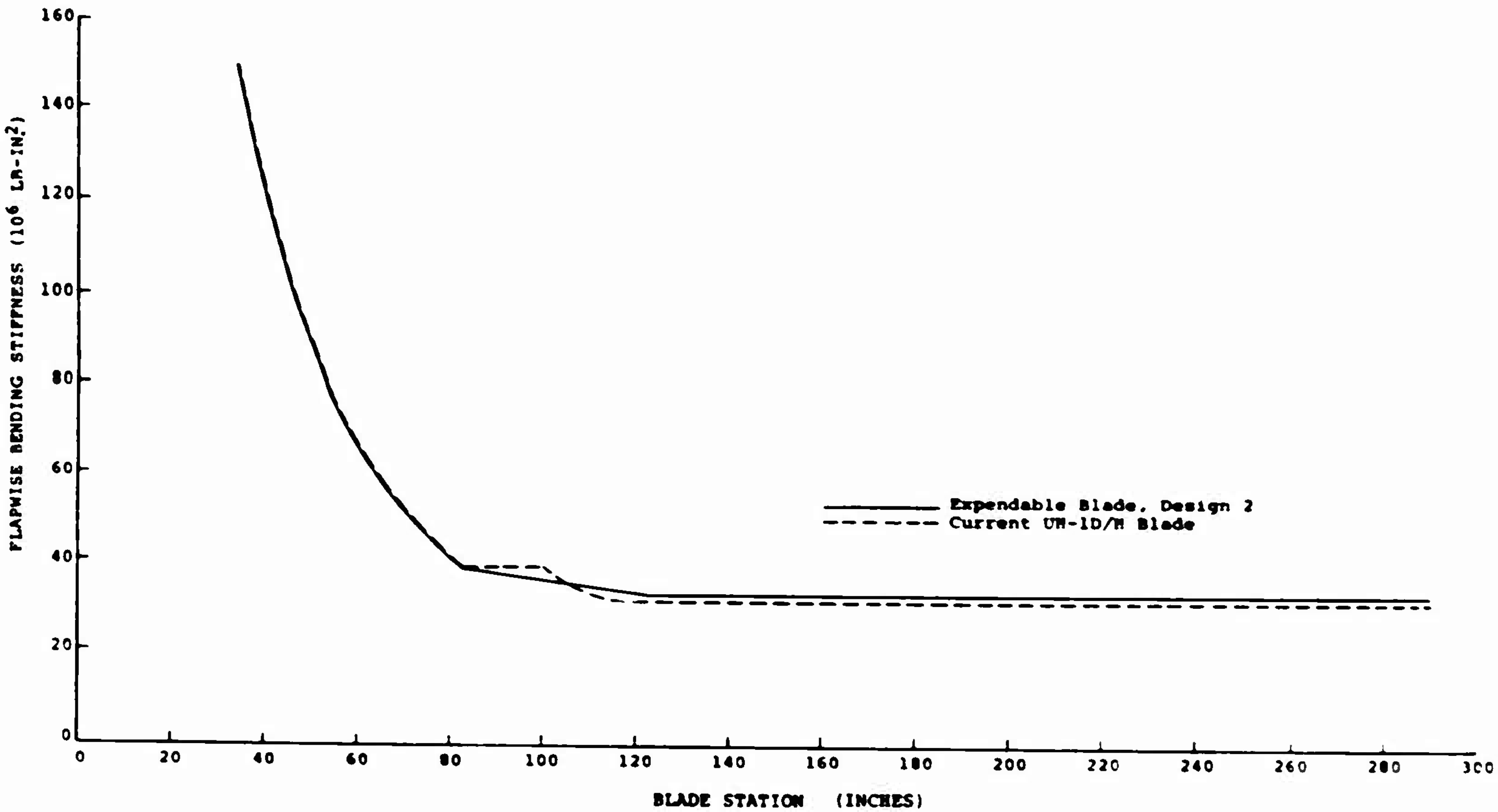

Figure 14. Flapwise Bending Stiffness, Design 2.

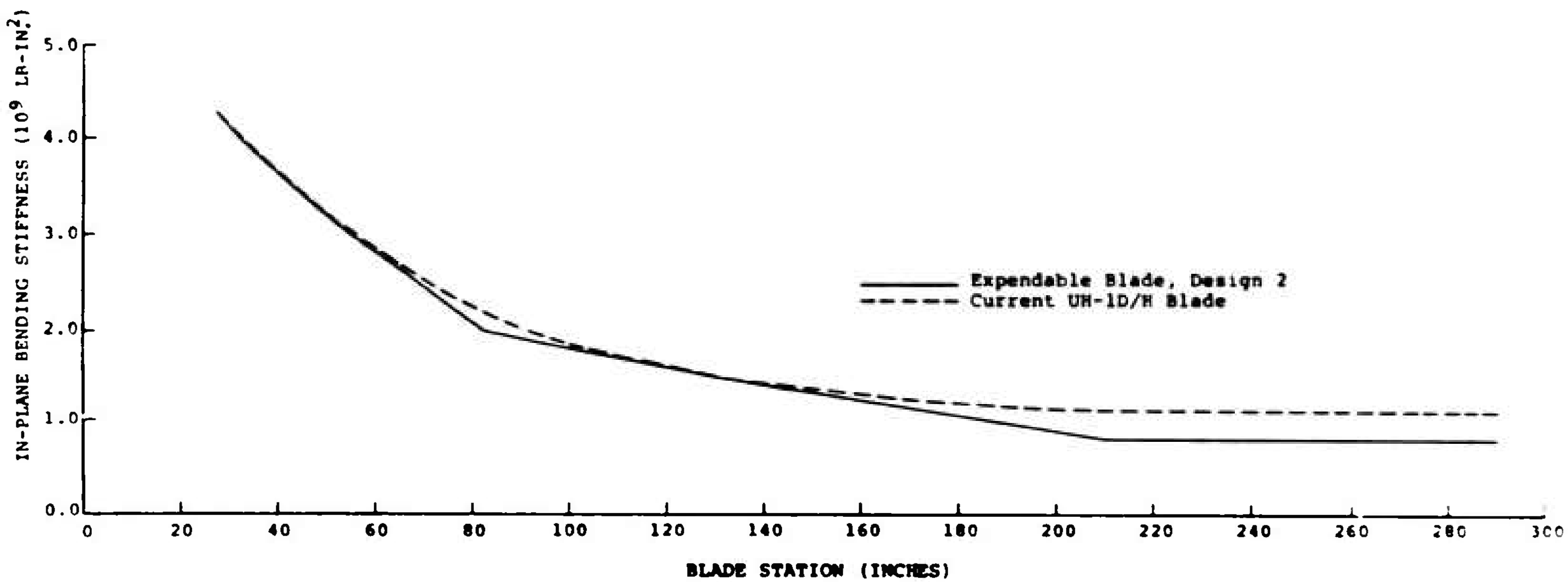

Figure 15. In-Plane Bending Stiffness, Design 2.

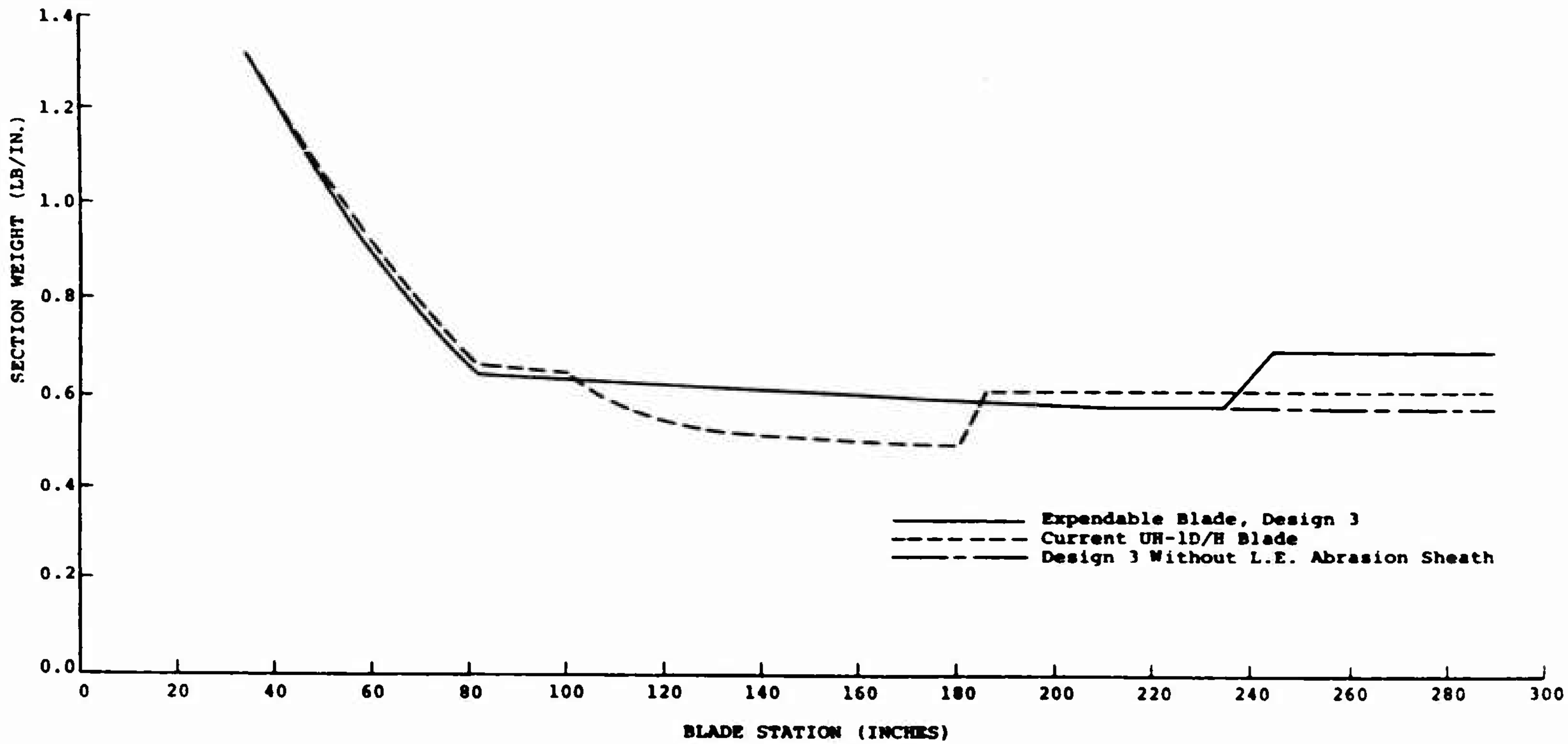

Figure 16. Weight Distribution, Design 3.

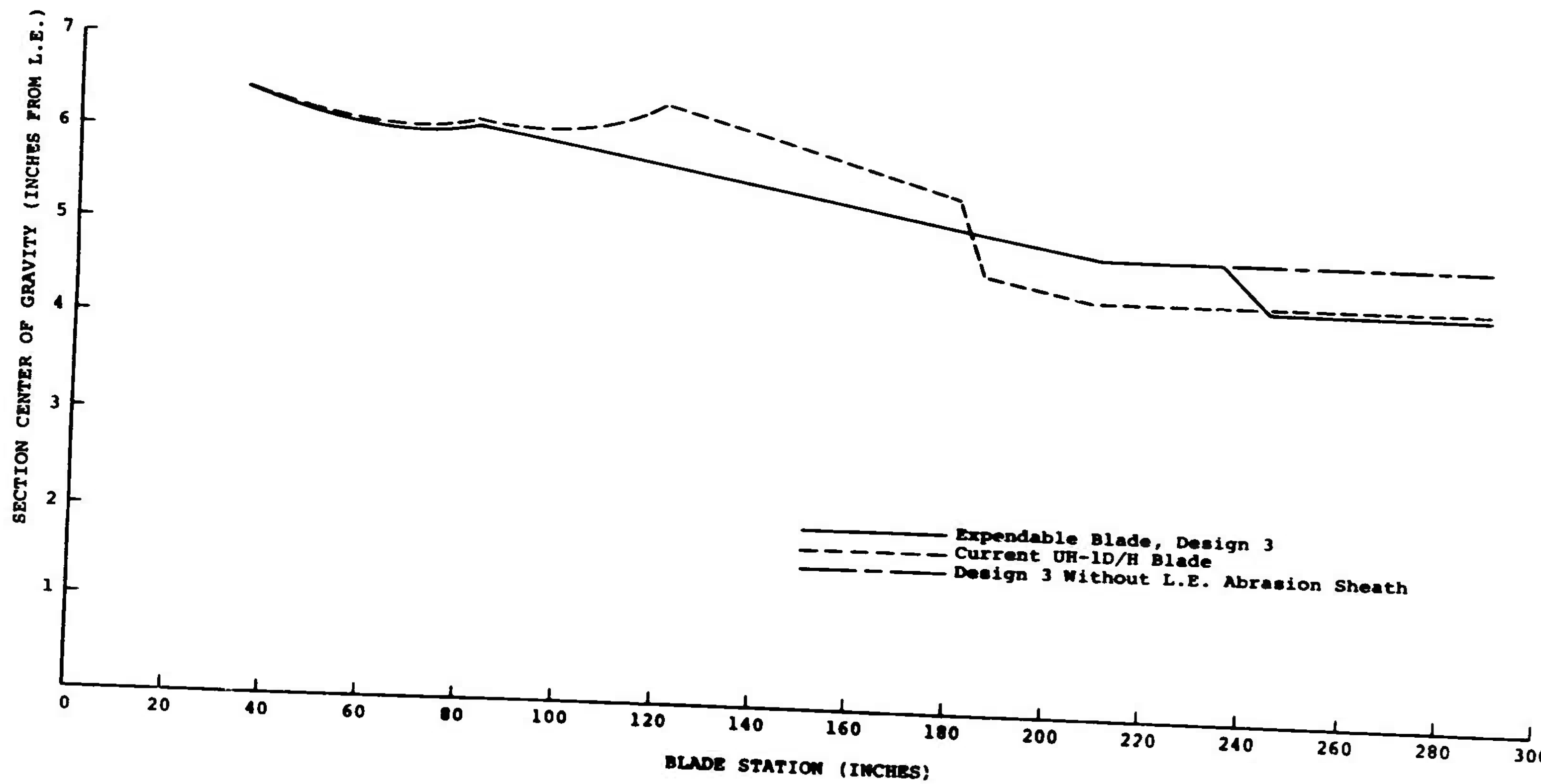

Figure 17. Center of Gravity, Design 3.

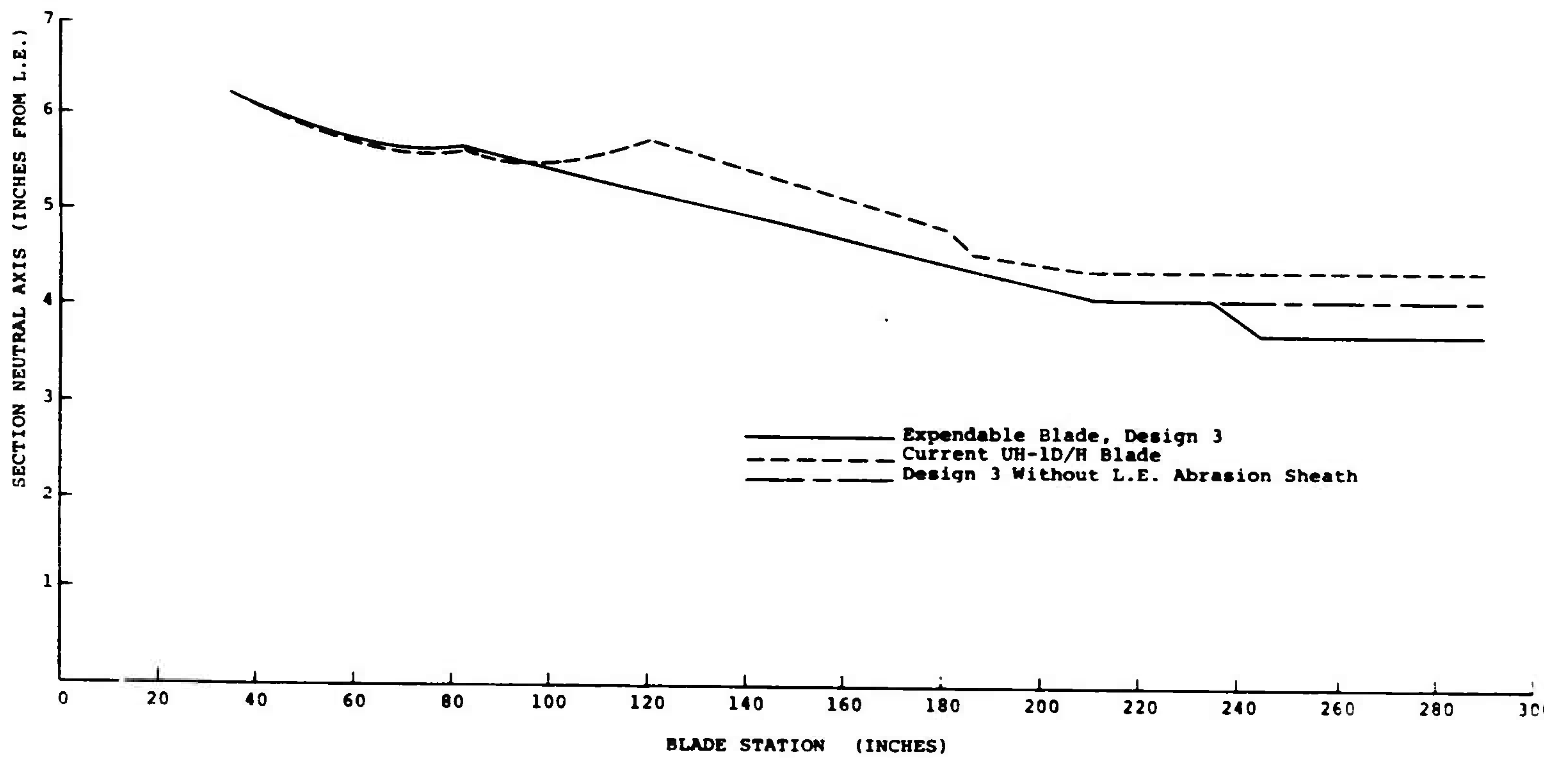

Figure 18. Neutral Axis, Design 3.

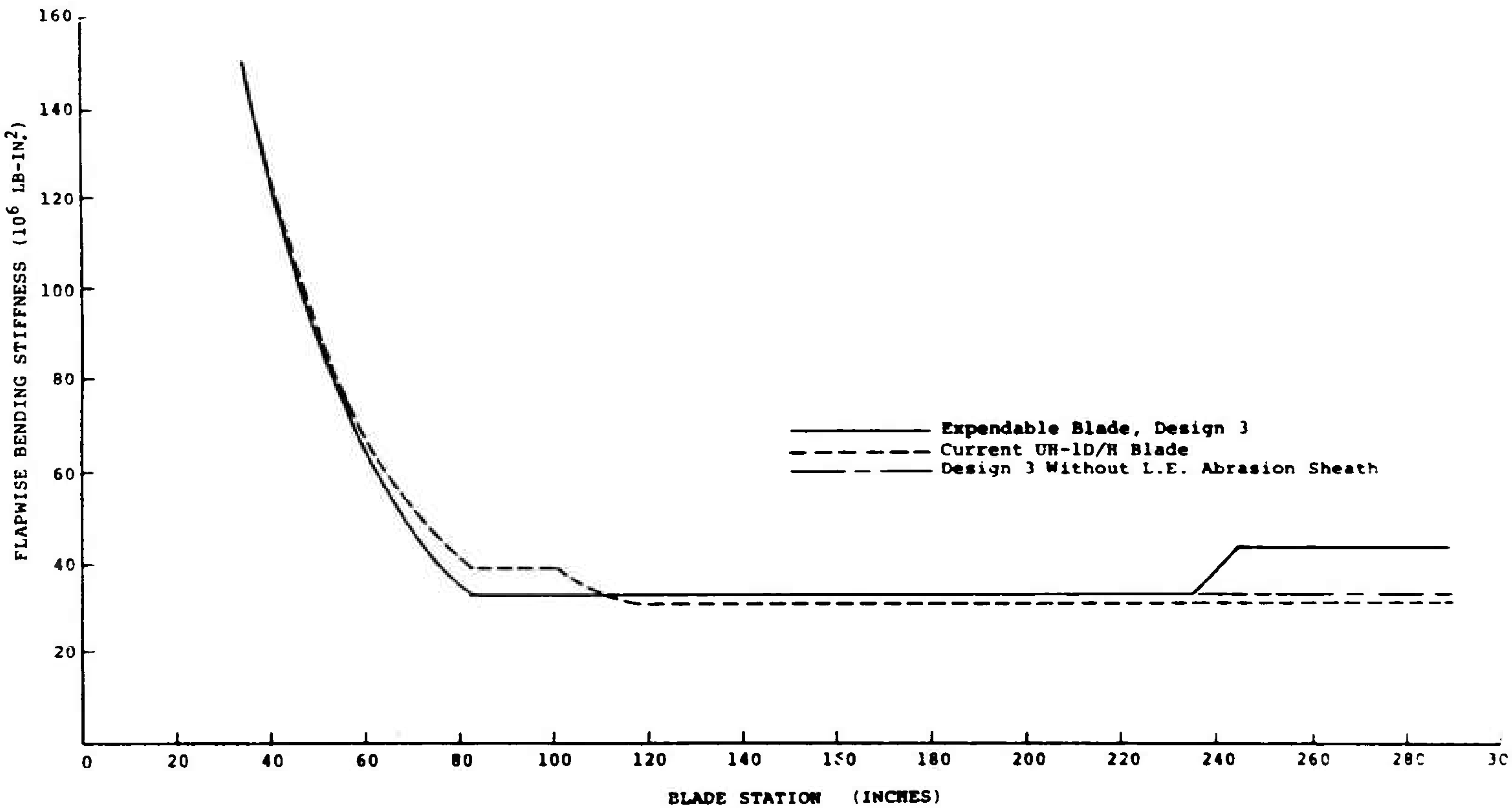

Figure 19. Flapwise Bending Stiffness, Design 3.

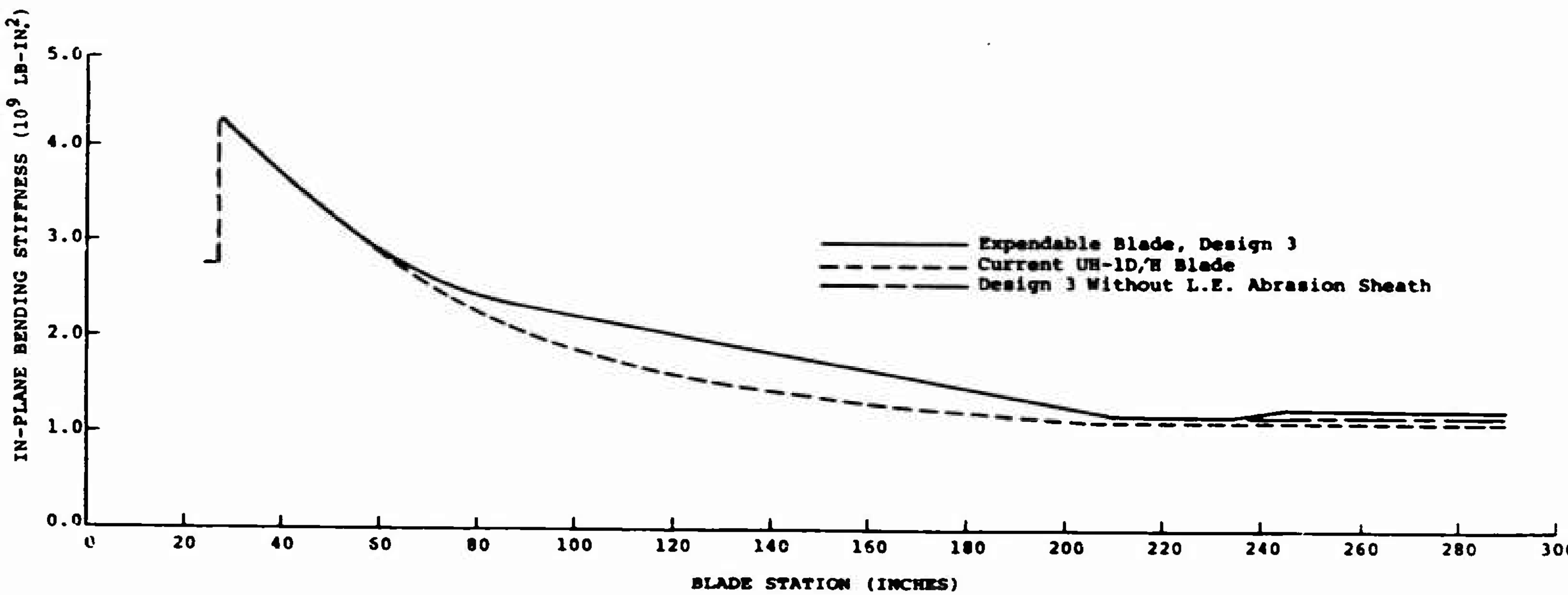

Figure 20. In-Plane Bending Stiffness, Design 3.

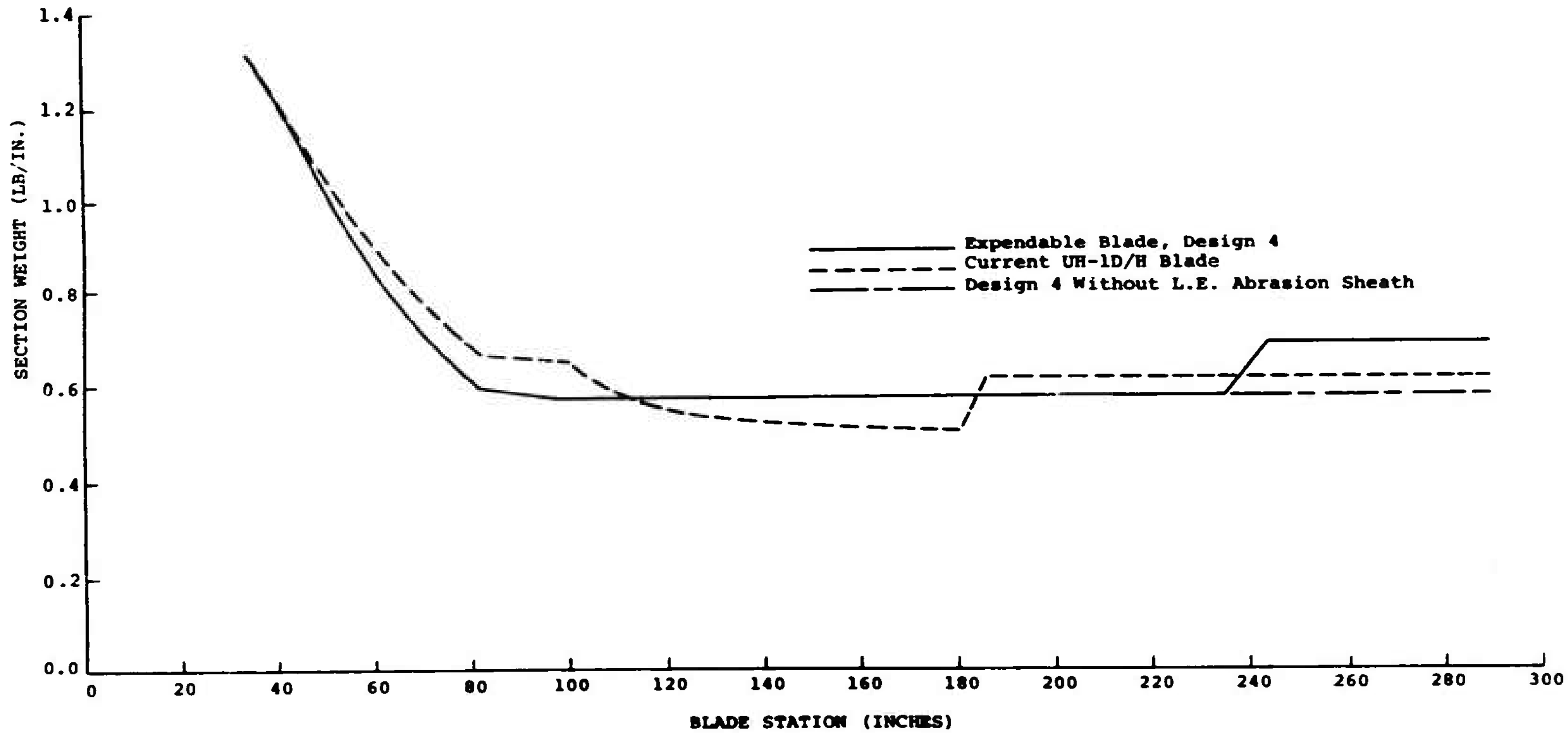

Figure 21. Weight Distribution, Design 4.

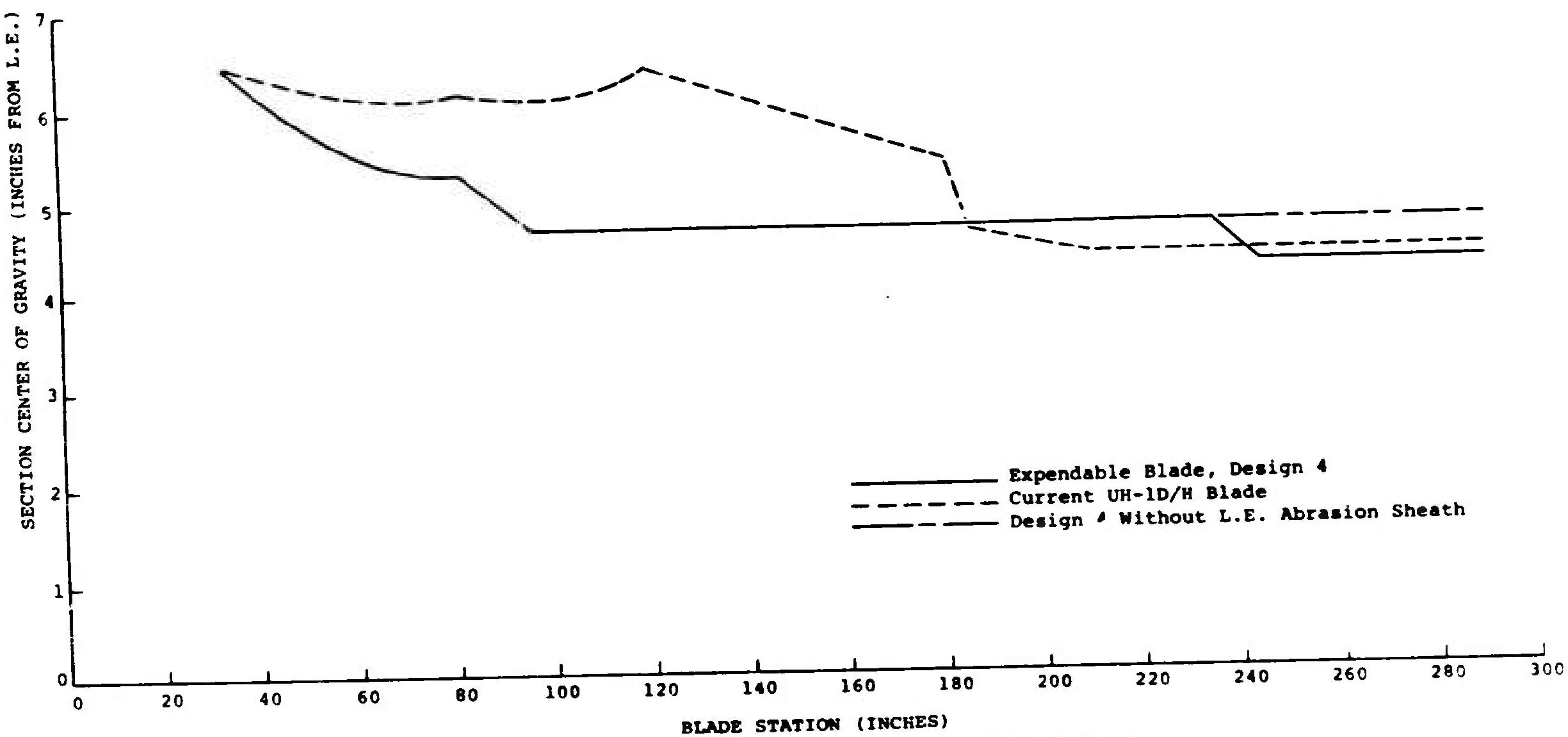

Figure 22. Center of Gravity, Design 4.

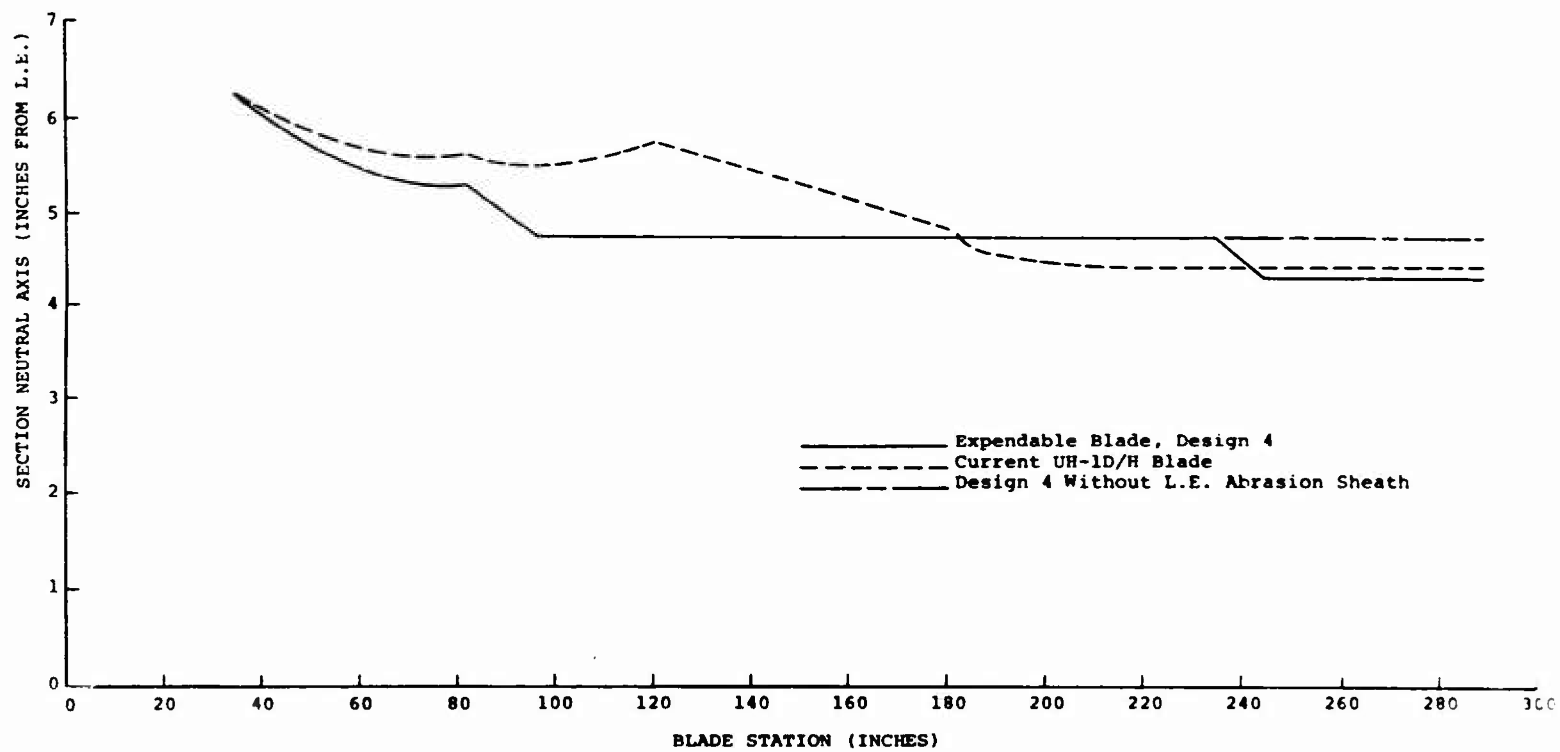

Figure 23. Neutral Axis, Design 4.

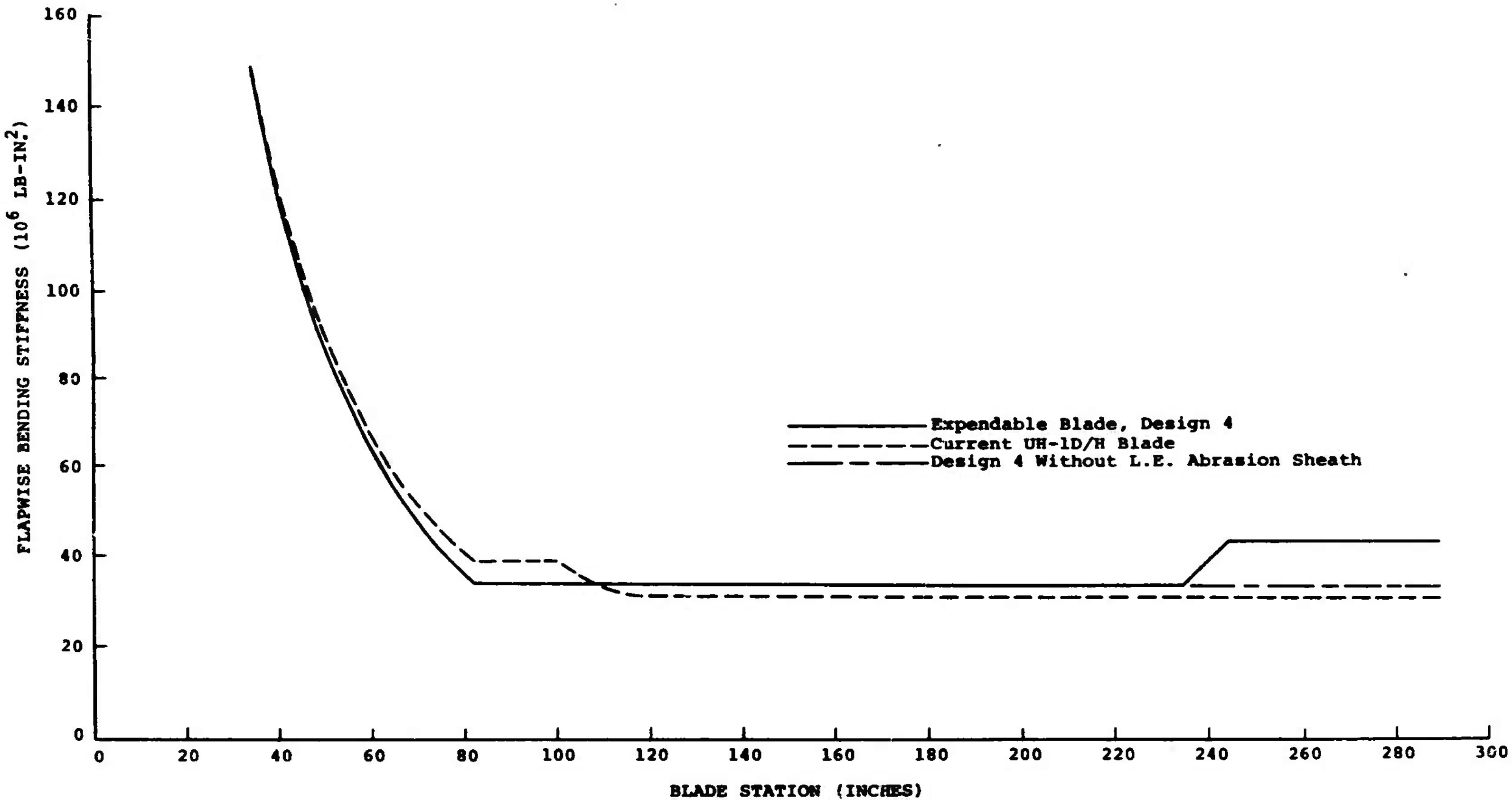

Figure 24. Flapwise Bending Stiffness, Design 4.

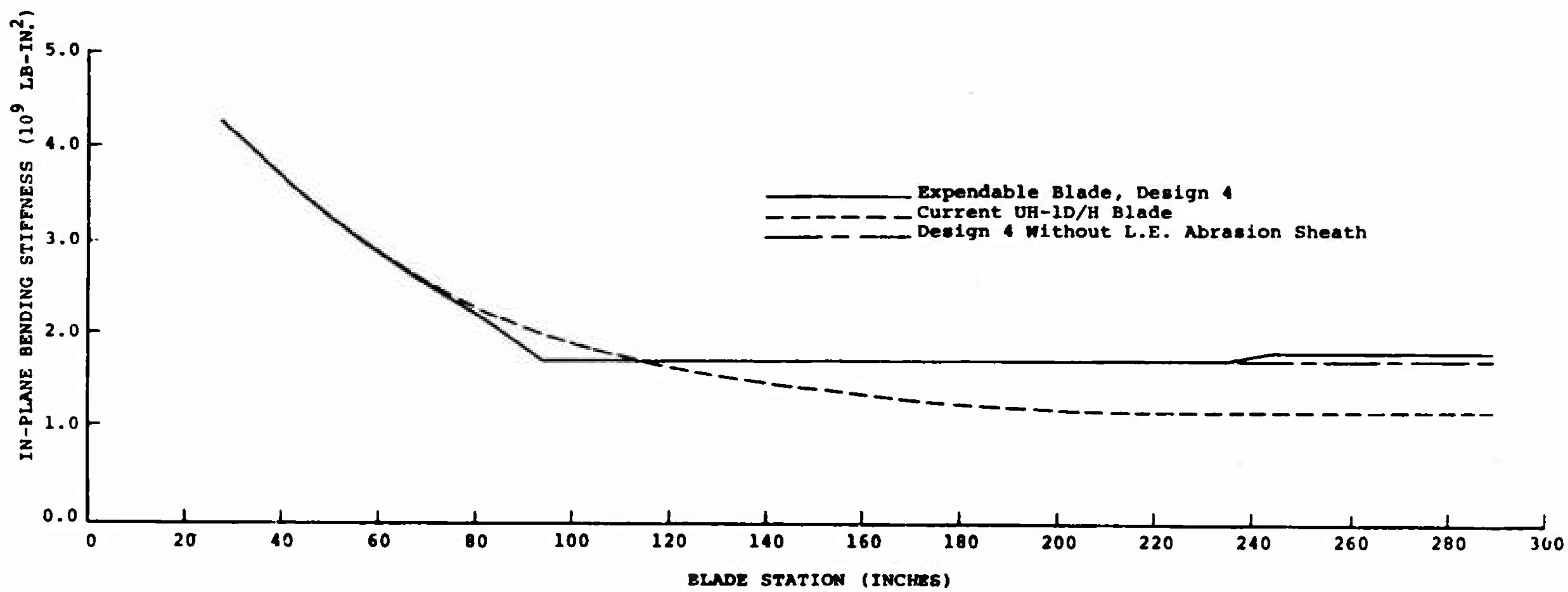

Figure 25. In-Plane Bending Stiffness, Design 4.

WEIGHT AND BALANCE PROPERTIES

The contractor has developed a computer program which integrates the section weight distribution and section center of gravity curves to give the overall mass parameters for the total blade. Total weight, spanwise moment and center of gravity, static and dynamic (i.e., span-weighted) hordwise centers of gravity, rotational inertia, and centrifugal force and static (droop) bending moment distributions are found by this program. By including the section flapwise bending stiffnesses, the static droop deflection curve is found, and including the section neutral axes allows computation of the distribution of in-plane bending moment due to offset of the centrifugal force vector.

Table II presents the total blade weight, the spanwise moment about the center of rotation and the center-of-gravity distance from the center of rotation, the static chordwise center of gravity distance from the leading edge, the location of the dynamic axis (i.e., span-weighted chordwise center of gravity), and the rotational inertia. The values for the current blade were determined by the same computer program, to provide a valid basis for comparison.

The centrifugal force distribution, centrifugal bending distribution, static bending moment distribution, and static deflection are plotted in Figures 26 through 33 for each of the four designs studied. Figures 26 through 29 present the centrifugal loadings for Designs 1 through 4 respectively, and Figures 30 through 33 present the static bending characteristics. For comparison, the curves calculated by the same computer program for the current blade are plotted as broken lines on each of the figures.

For the three designs (1, 3, and 4) utilizing extruded aluminum spars, results are presented both with and without the leading-edge abrasion sheath; and for Design 2, results are presented with and without tip weights. A third version of each of Designs 1 and 3 is presented in Table II. In these, the blade was further modified by reducing the integral nose ballast, resulting in close agreement with the current blade. These results show that careful detail design can achieve weight and balance and overall dynamic properties virtually identical with those of the current UH-1H blade, with consequently negligible differences in flying qualities. Detail design of the required order of accuracy must be accompanied by a detailed weight breakdown and analysis, which is not appropriate during the preliminary design and feasibility study phases. Table II illustrates the feasibility

TABLE II. COMPARISON OF PHYSICAL PROPERTIES

Blade Configuration	Total Weight (Pounds)	Moment About Center of Rotation (Lb-In.)	Spanwise Center of Gravity (In. from C.R.)	Chordwise Center of Gravity (In. from L.E.)	Dynamic Mass Axis (In. from L.E.)	Inertia About Center of Rotation (Slug - Ft^2)
Current UH-1H	182.08	26112	143.41	5.554	5.103	1075
Design 1						
No Abrasion Sheath	185.59	26178	141.05	5.498	5.122	1051
With Abrasion Sheath	191.11	27635	144.60	5.395	4.954	1134
Ballast Reduced	182.12	26106	143.35	5.593	5.164	1069
Design 2						
No Tip Weights	178.49	24805	138.97	5.404	4.990	989
With Tip Weights	181.87	25770	141.70	5.415	5.028	1049
Design 3						
No Abrasion Sheath	181.57	25487	140.37	5.594	5.260	1021
With Abrasion Sheath	187.09	26944	144.02	5.486	5.081	1104
Ballast Reduced	182.08	26093	143.31	5.599	5.201	1068
Design 4						
No Abrasion Sheath	174.89	24636	140.87	5.164	4.682	994
With Abrasion Sheath	180.65	26156	144.80	5.064	4.716	1081

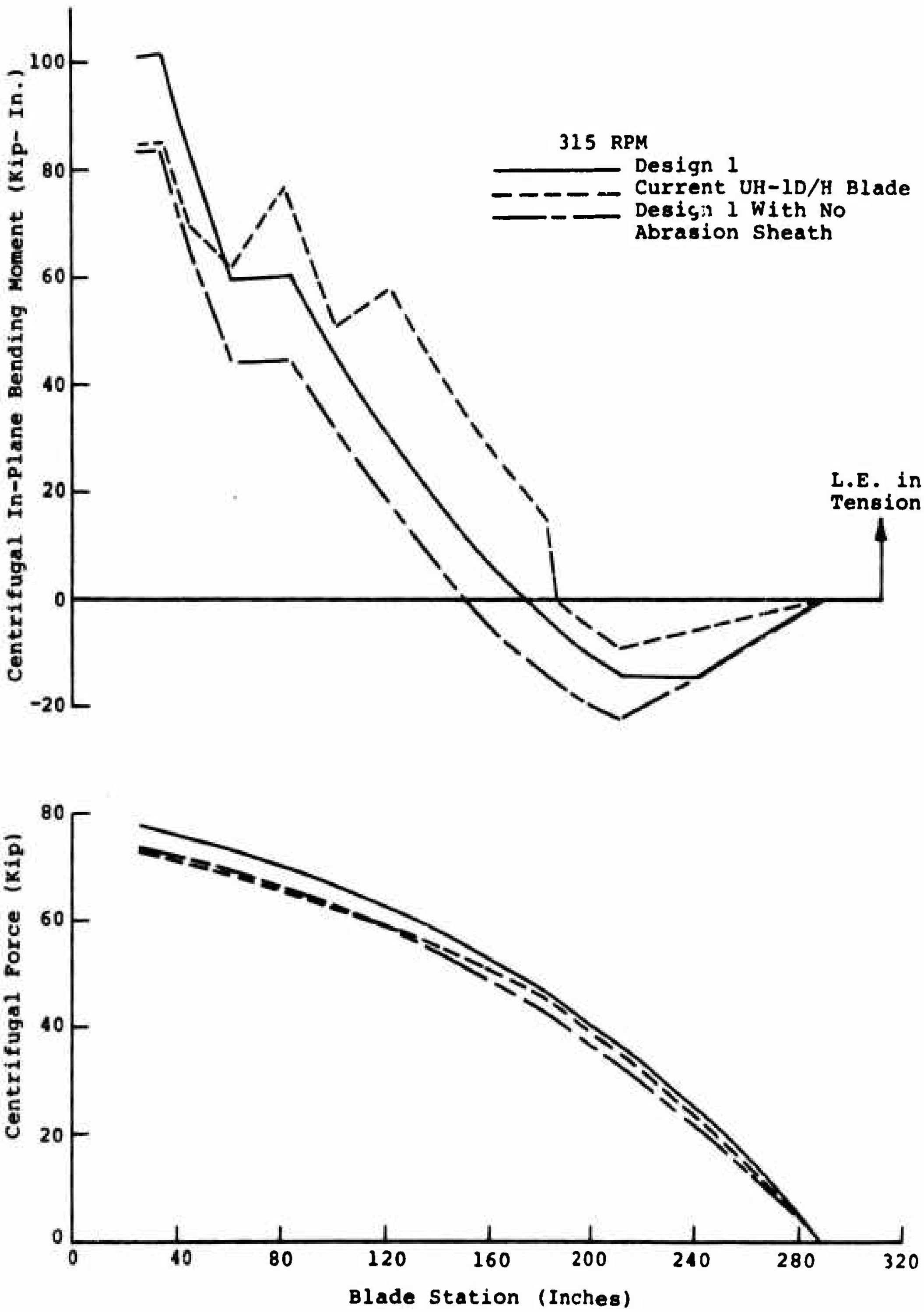

Figure 26. Centrifugal Loading, Design 1.

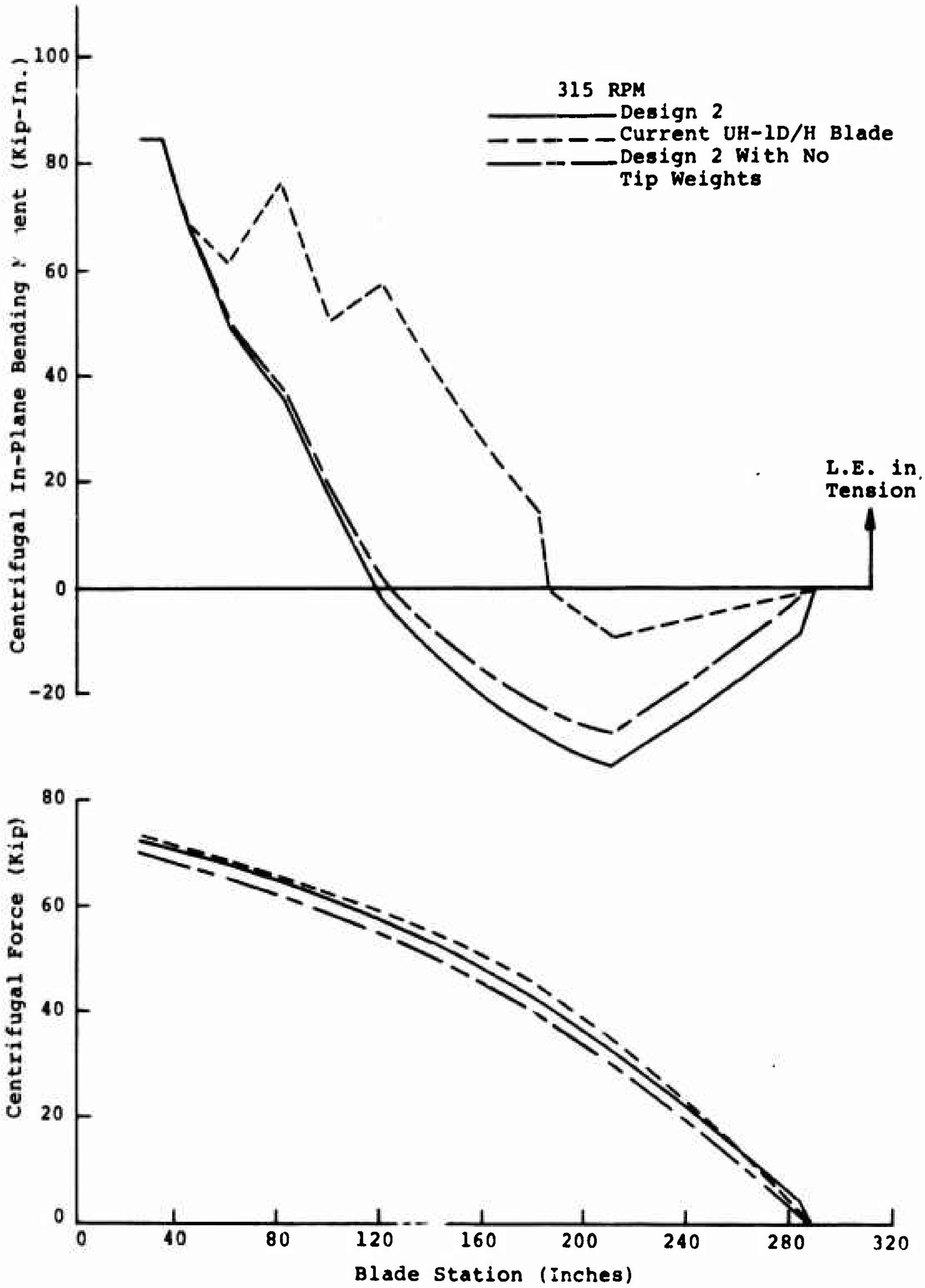

Figure 27. Centrifugal Loading, Design 2.

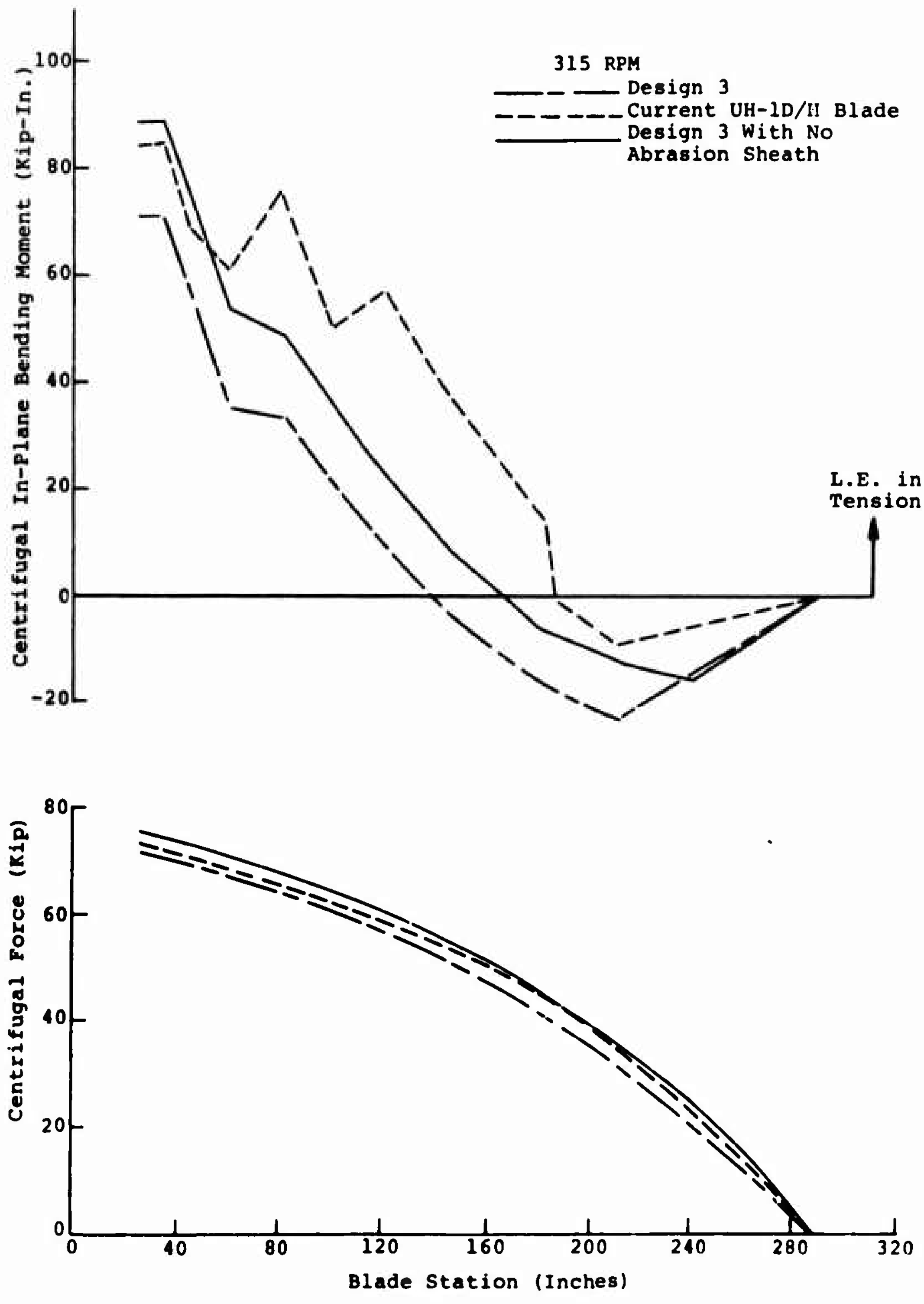

Figure 28. Centrifugal Loading, Design 3.

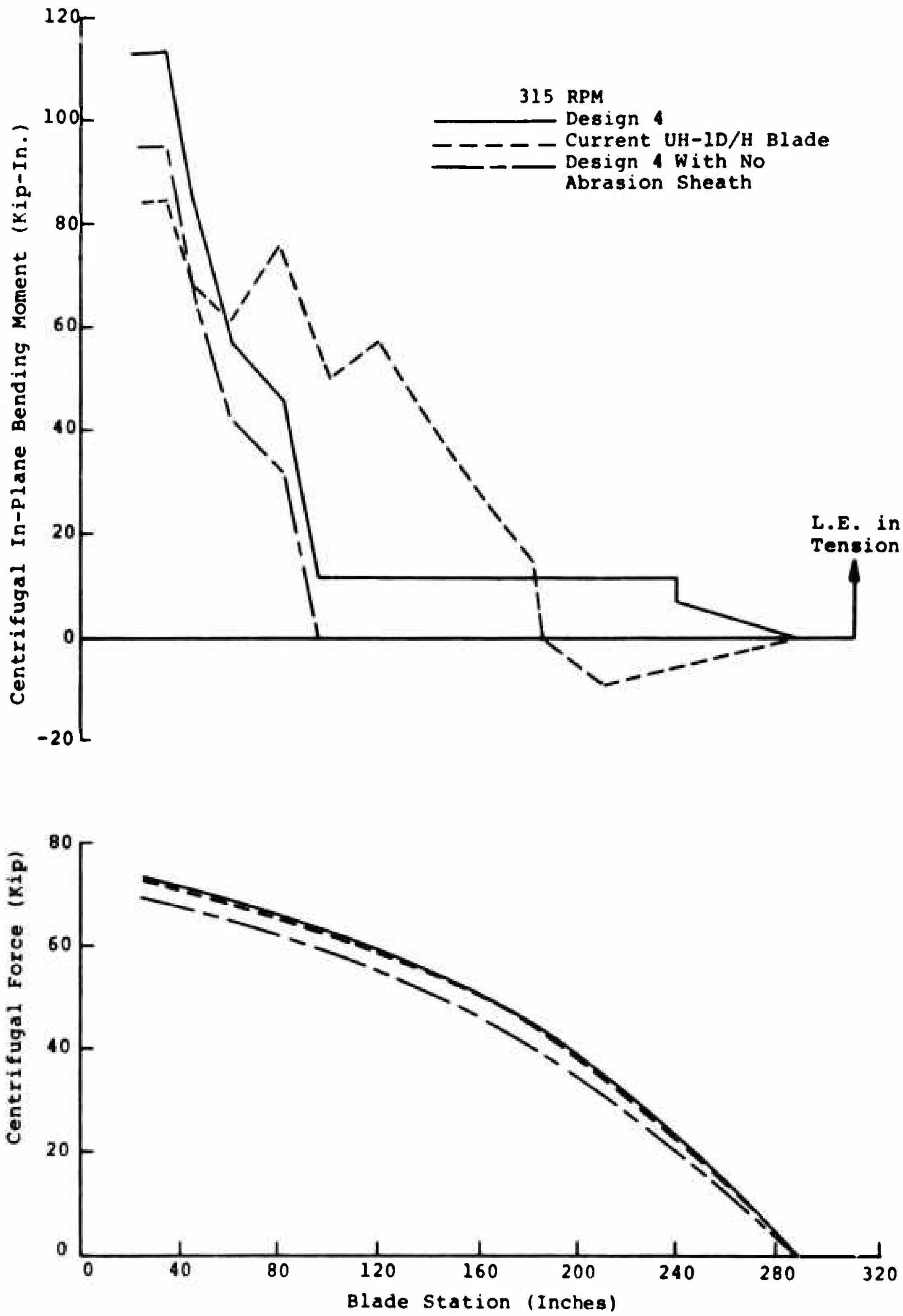

Figure 29. Centrifugal Loading, Design 4.

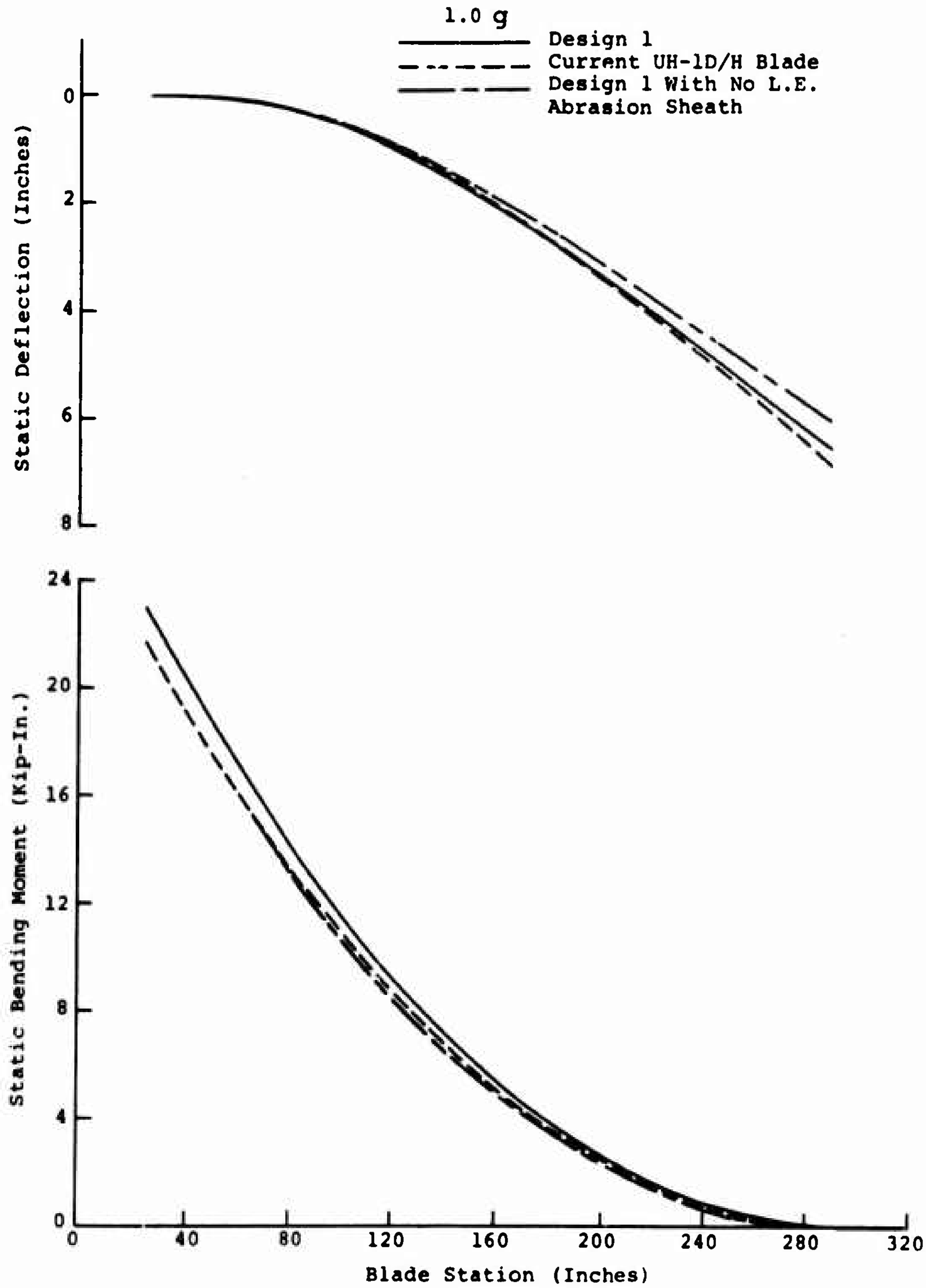

Figure 30. Static Bending, Design 1.

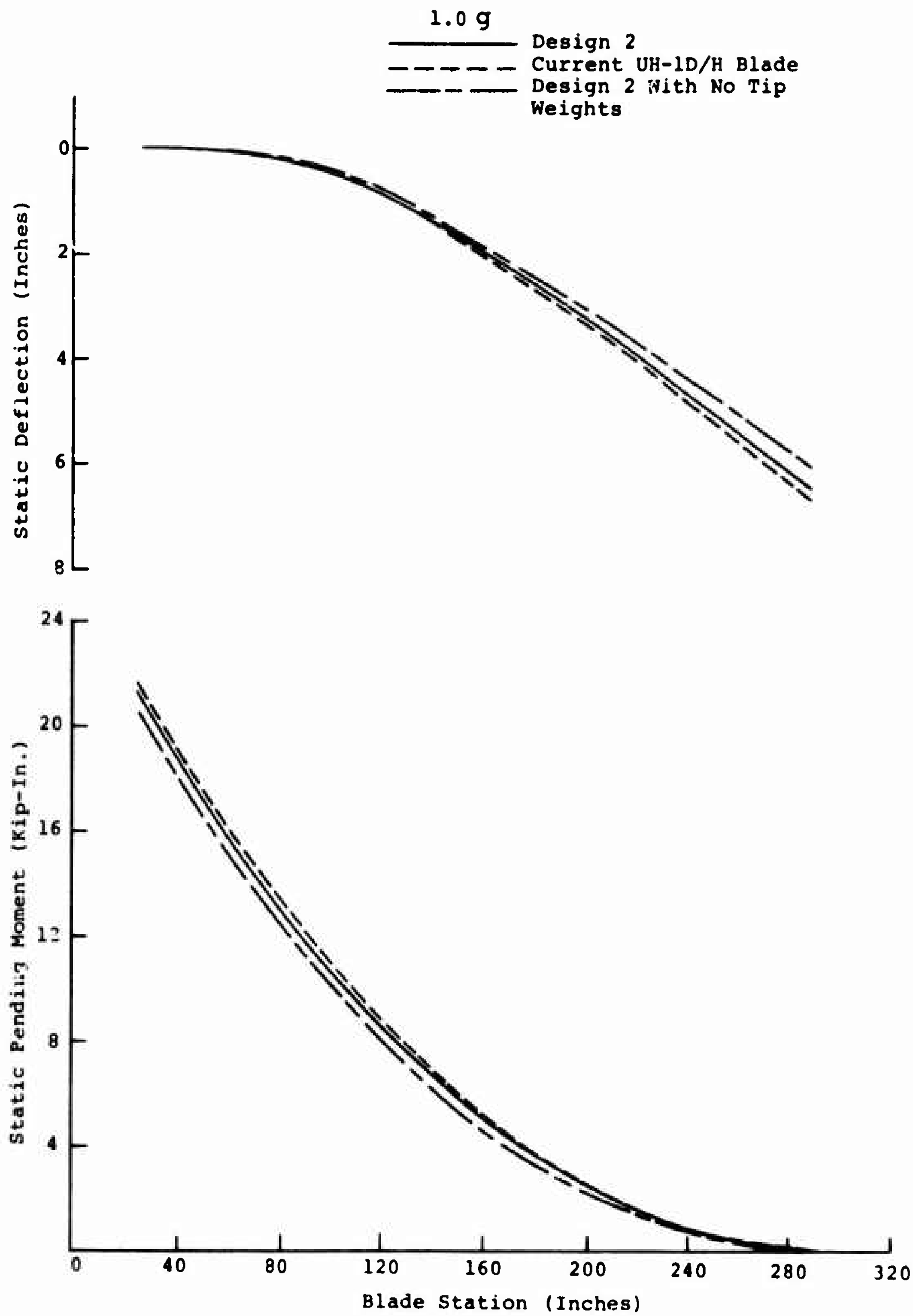

Figure 31. Static Bending, Design 2.

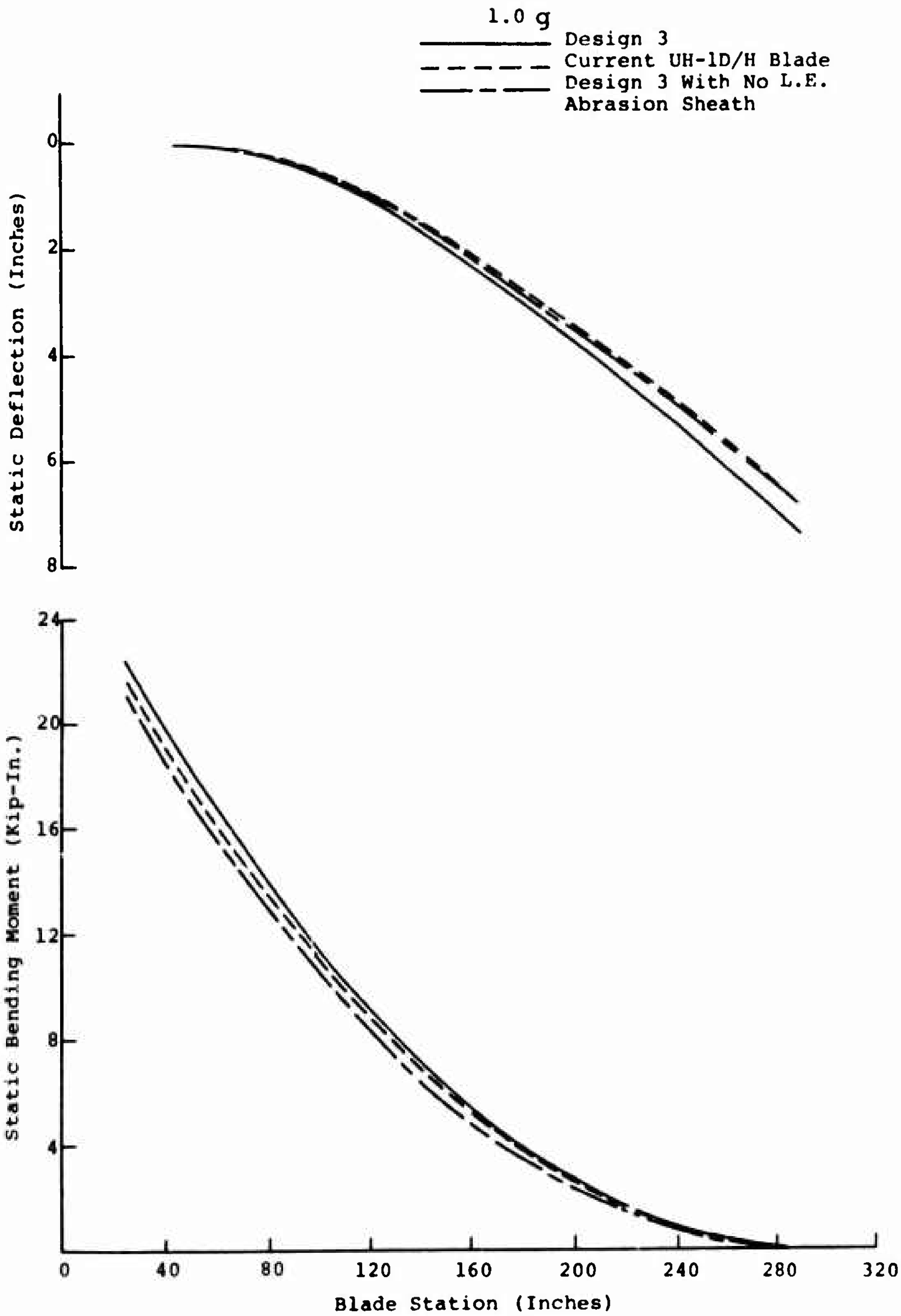

Figure 32. Static Bending, Design 3.

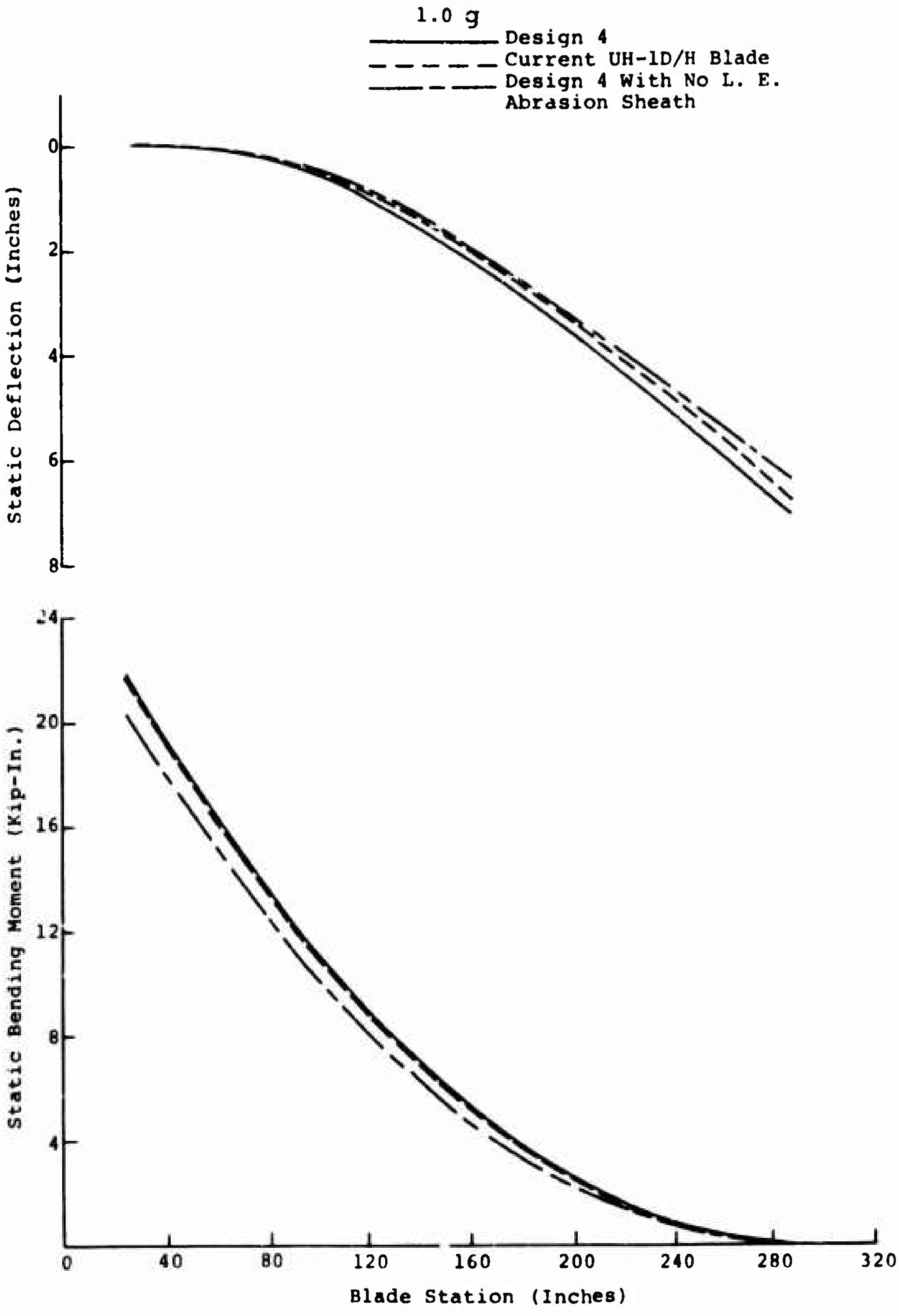

Figure 33. Static Bending, Design 4.

of the approaches taken in Designs 1, 2, and 3, and shows that the overall physical properties cannot be quite so easily duplicated with Design 4.

DYNAMIC PROPERTIES

The contractor's computer programs for rotor blade dynamics and air loads were utilized to obtain the natural frequencies and dynamic bending moments for each of the expendable blade concepts. Resonance diagrams for the three lowest out-of-plane modes, both pin-ended and cantilever, and the two lowest in-plane cantilever modes were obtained. The dynamic blade bending moments were determined for steady level flight at 9500 pounds gross weight and 107 knots.

The air loads for the blade dynamic analysis were derived by a computer program, which is essentially an improved version of the method described in Reference 3. The method was adapted for use on a teetering rotor by assuming the blades to be connected to each other by a spring representing the stiffness of the hub, restricting independent flapping motion of the two blades.

The air loads determined as described above were utilized in the blade bending moment calculation by a computer program based on the method described in Reference 4.

The resonance diagrams for the current UH-1H main rotor blade and for the four concepts studied under this contract are plotted in Figures 34 through 37. In each of the figures, three resonance diagrams are superimposed, one of which is for the current blade, while the other two are for the uniform basic expendable blade design and for the expendable blade design incorporating the tip modifications described above (abrasion sheath on Designs 1, 3, and 4, and tip weights on Design 2). The curves plotted for the current blade are the same as those derived for and reported in Reference 1.

The dynamic bending moments, out-of-plane and in-plane, are plotted in Figures 38 through 45. Again, three curves are superimposed on each figure, presenting the results for the current blade and for the expendable blade design with and without the added tip mass. The curves for the current blade are again the same as those plotted in Reference 1.

In a rotor system having torsionally stiff blades, such as that of the UH-1H, vibratory pitching modes of importance to dynamic stability or stress level amplification occur primarily with the blades behaving as rigid bodies, most of the deflection occurring at the root. Consequently, the torsional stiffness of the blade is of minor importance, and dynamic requirements in torsion will be met if the expendable blade concepts are maintained as stiff, or almost as stiff, as the current UH-1H blade. Without detail analysis, it can be seen that for all of the expendable concepts, significant degradation of torsional stiffness has been avoided.

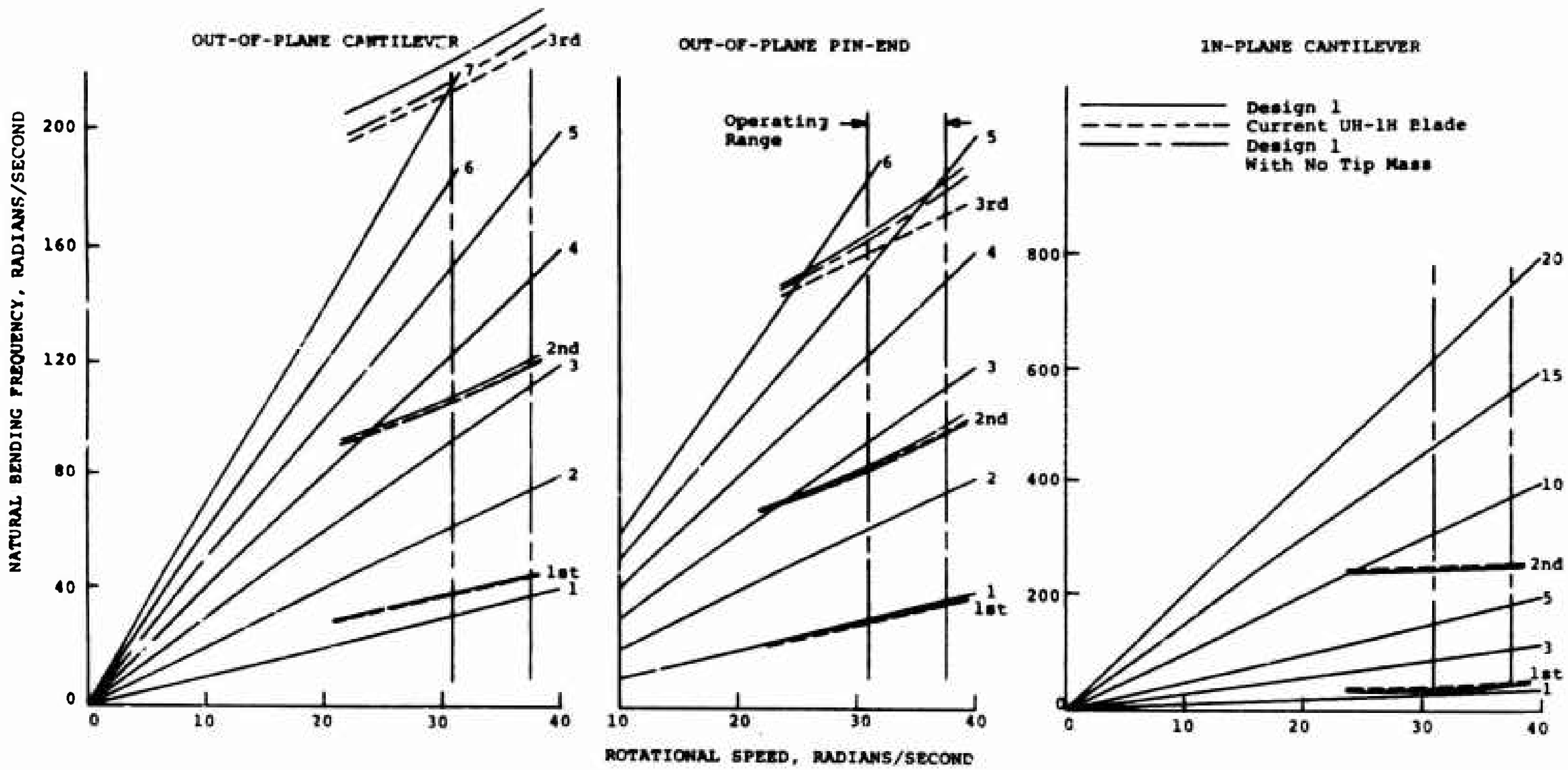

Figure 34. Natural Frequencies, Design 1.

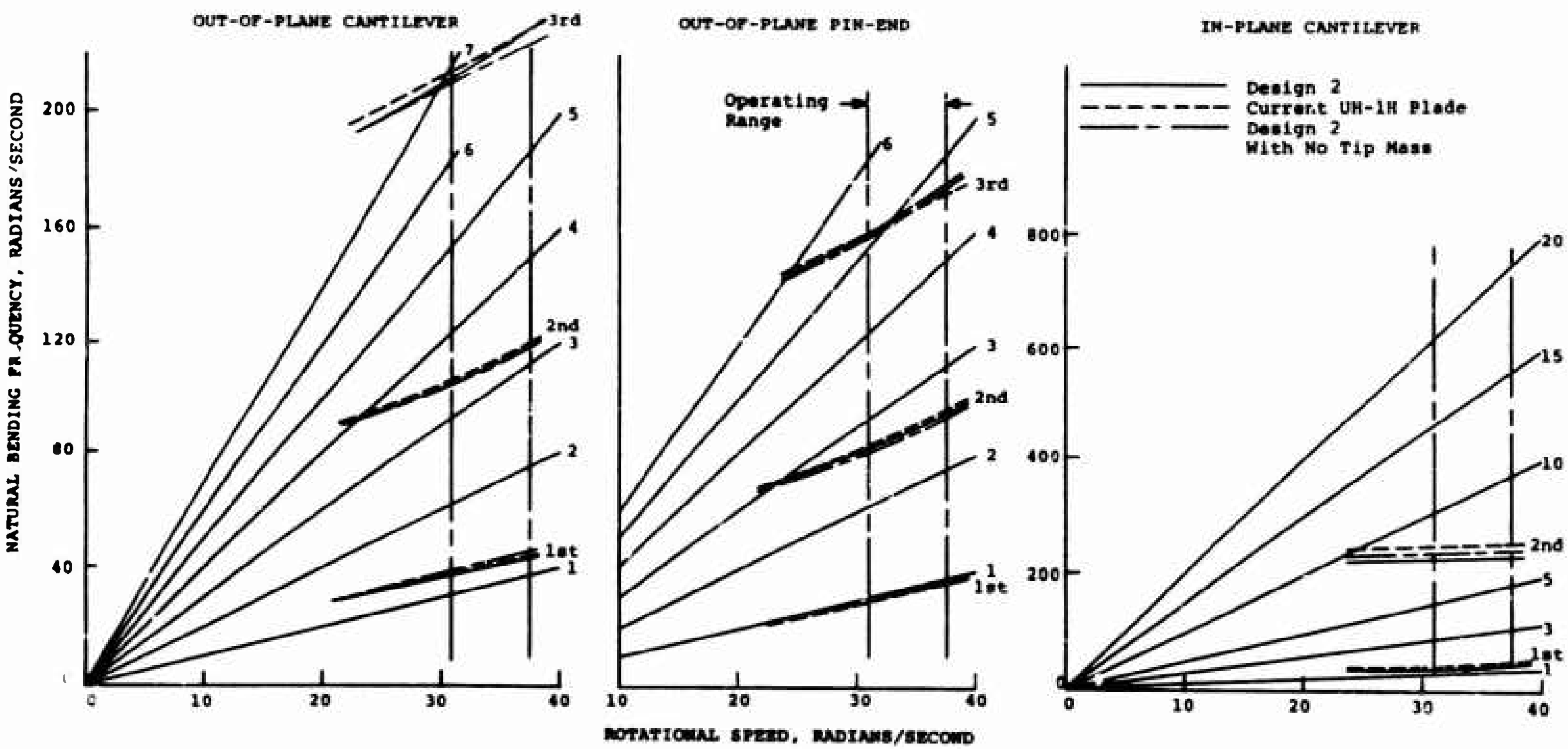

Figure 35. Natural Frequencies, Design 2.

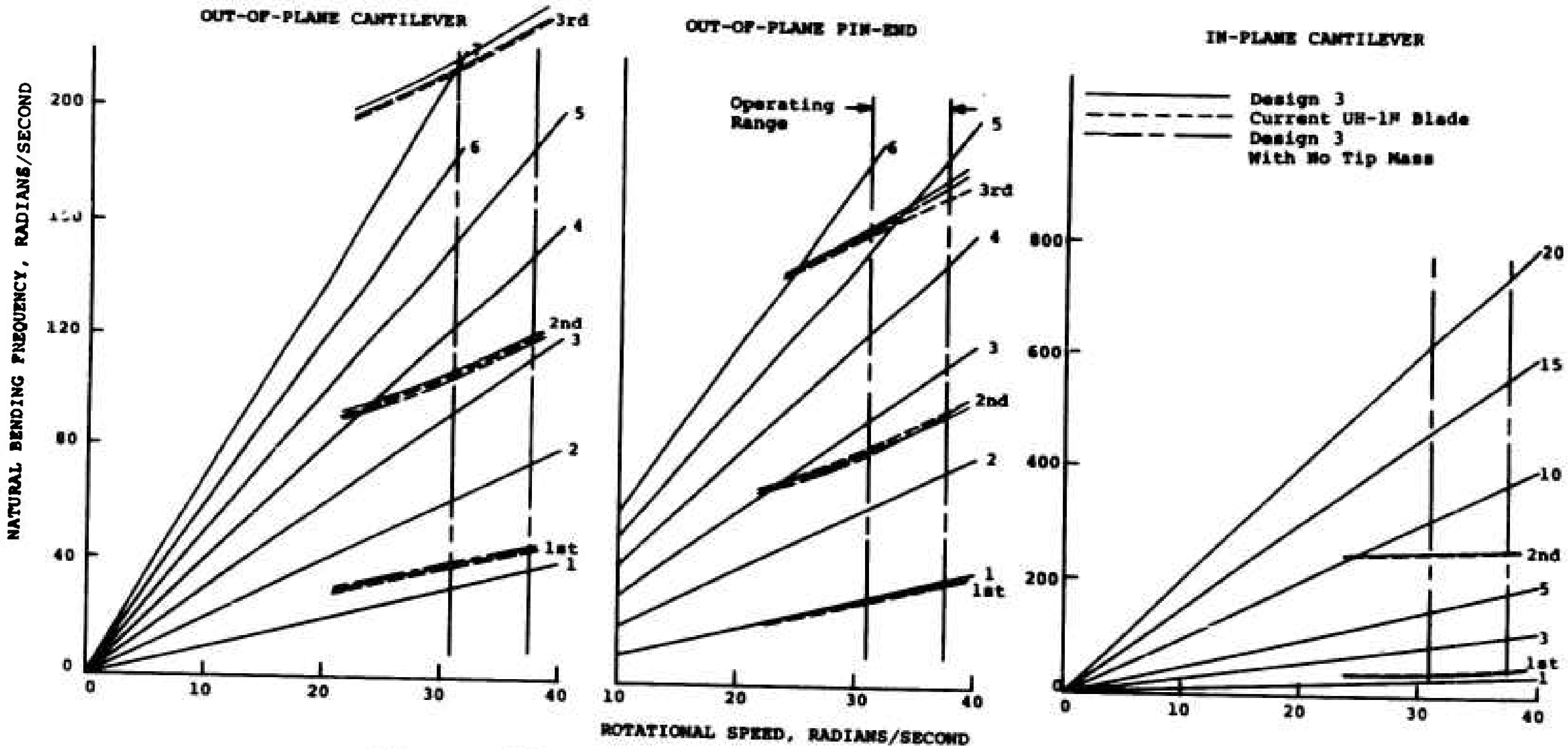

Figure 36. Natural Frequencies, Design 3.

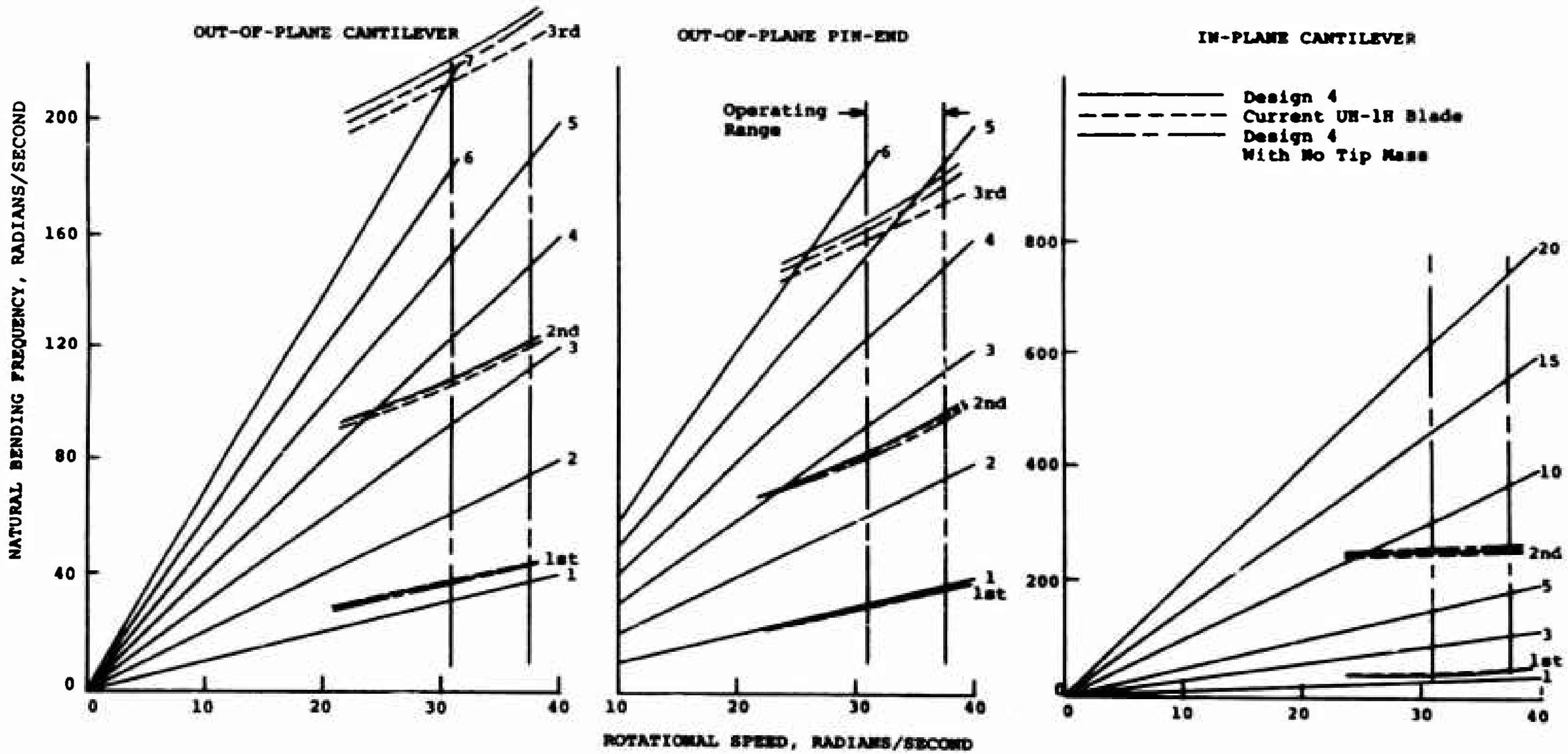

Figure 37. Natural Frequencies, Design 4.

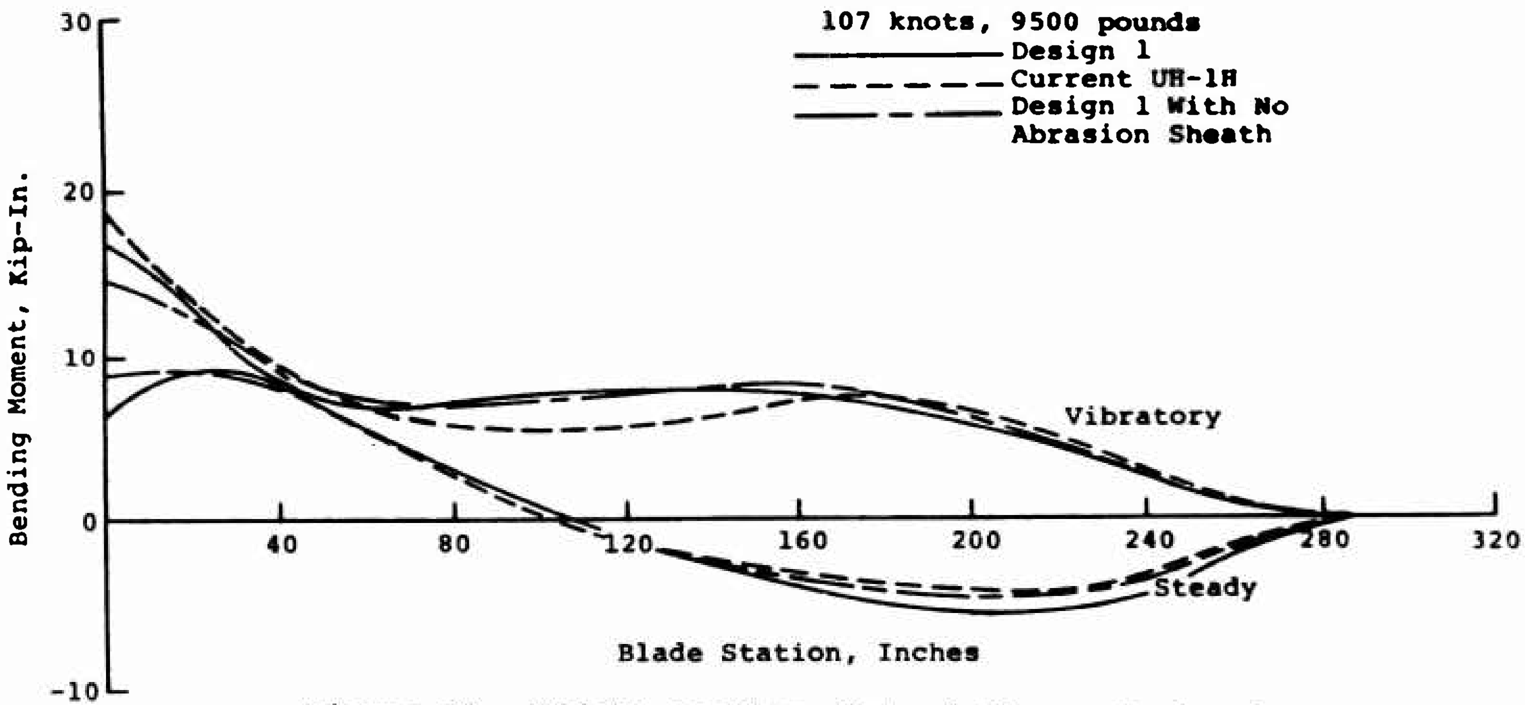

Figure 38. Flight Loading, Out-of-Plane, Design 1.

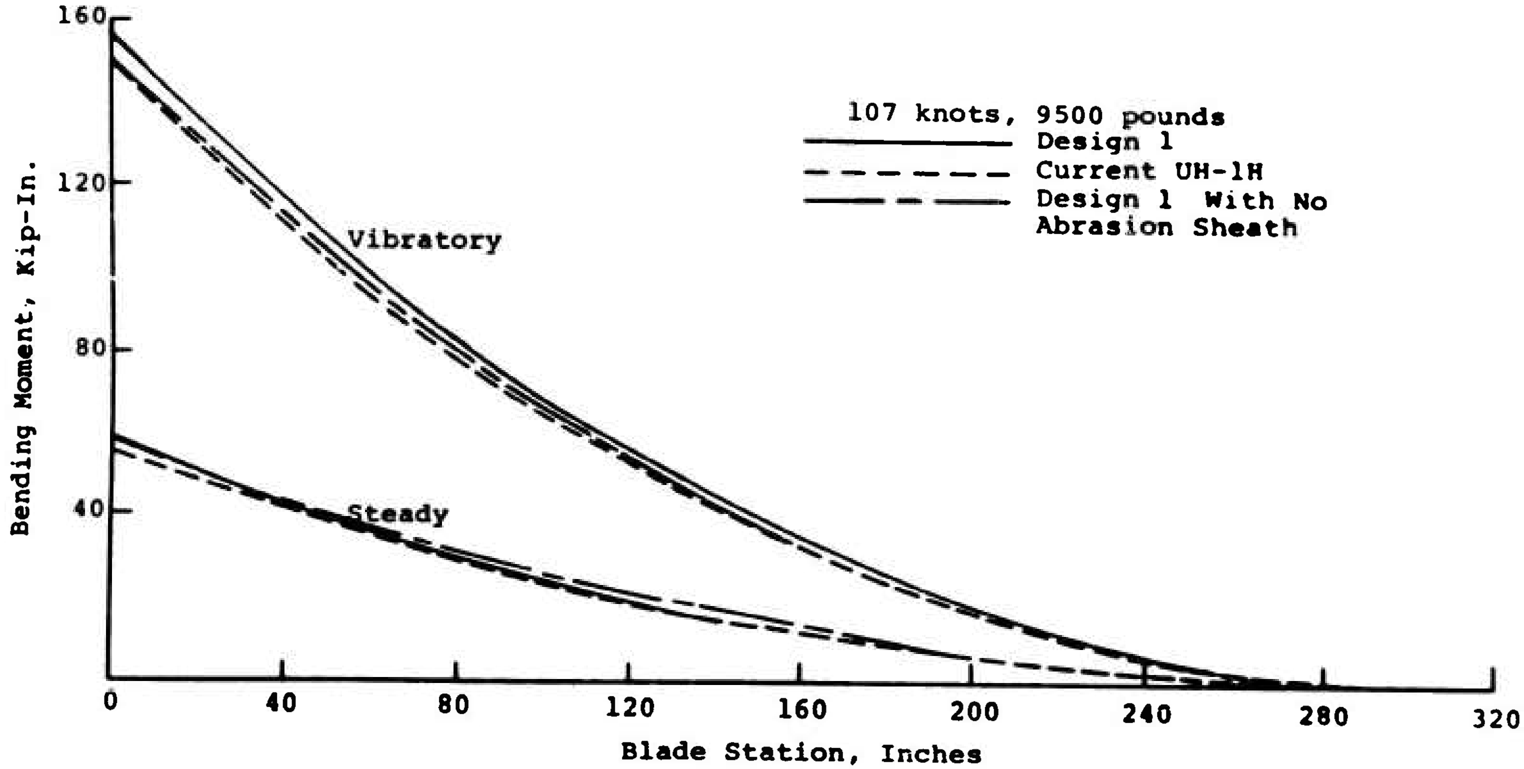

Figure 39. Flight Loading, In-Plane, Design 1.

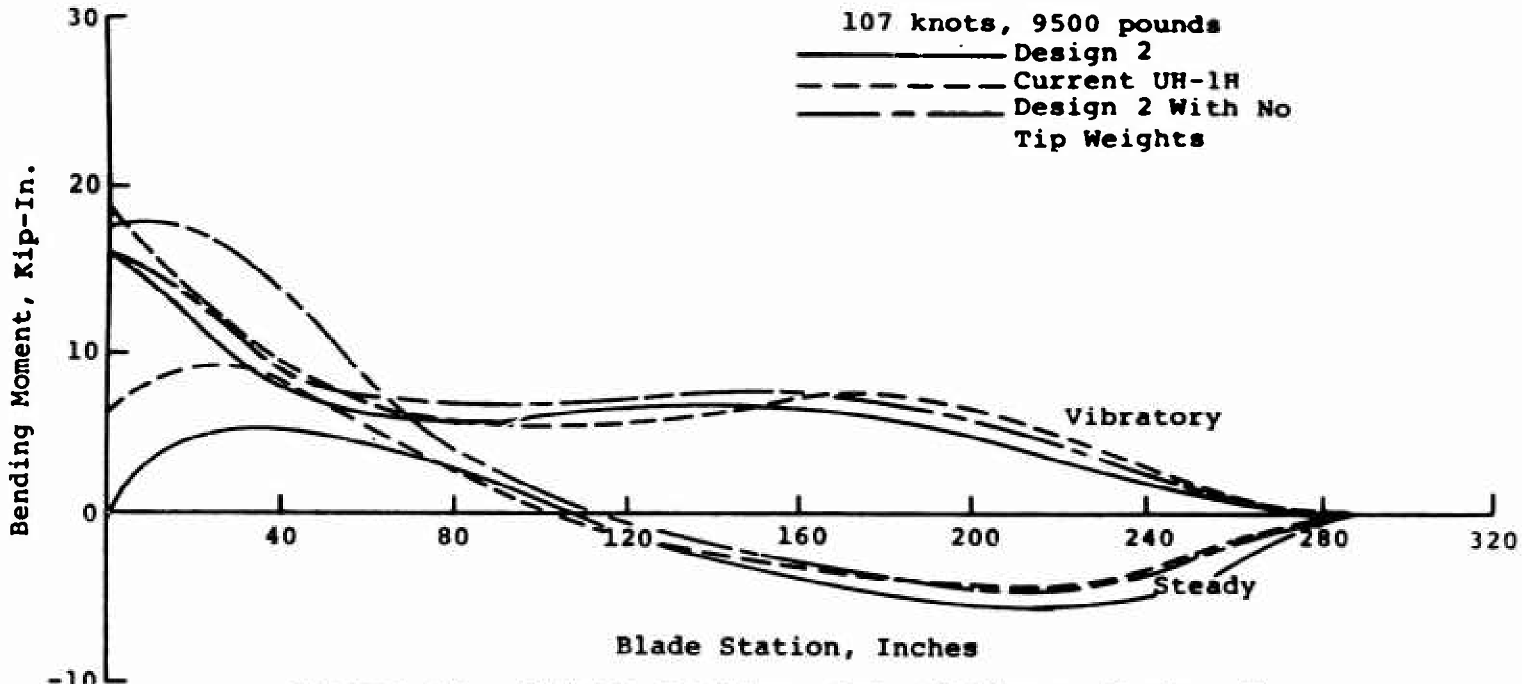

Figure 40. Flight Loading, Out-of-Plane, Design 2.

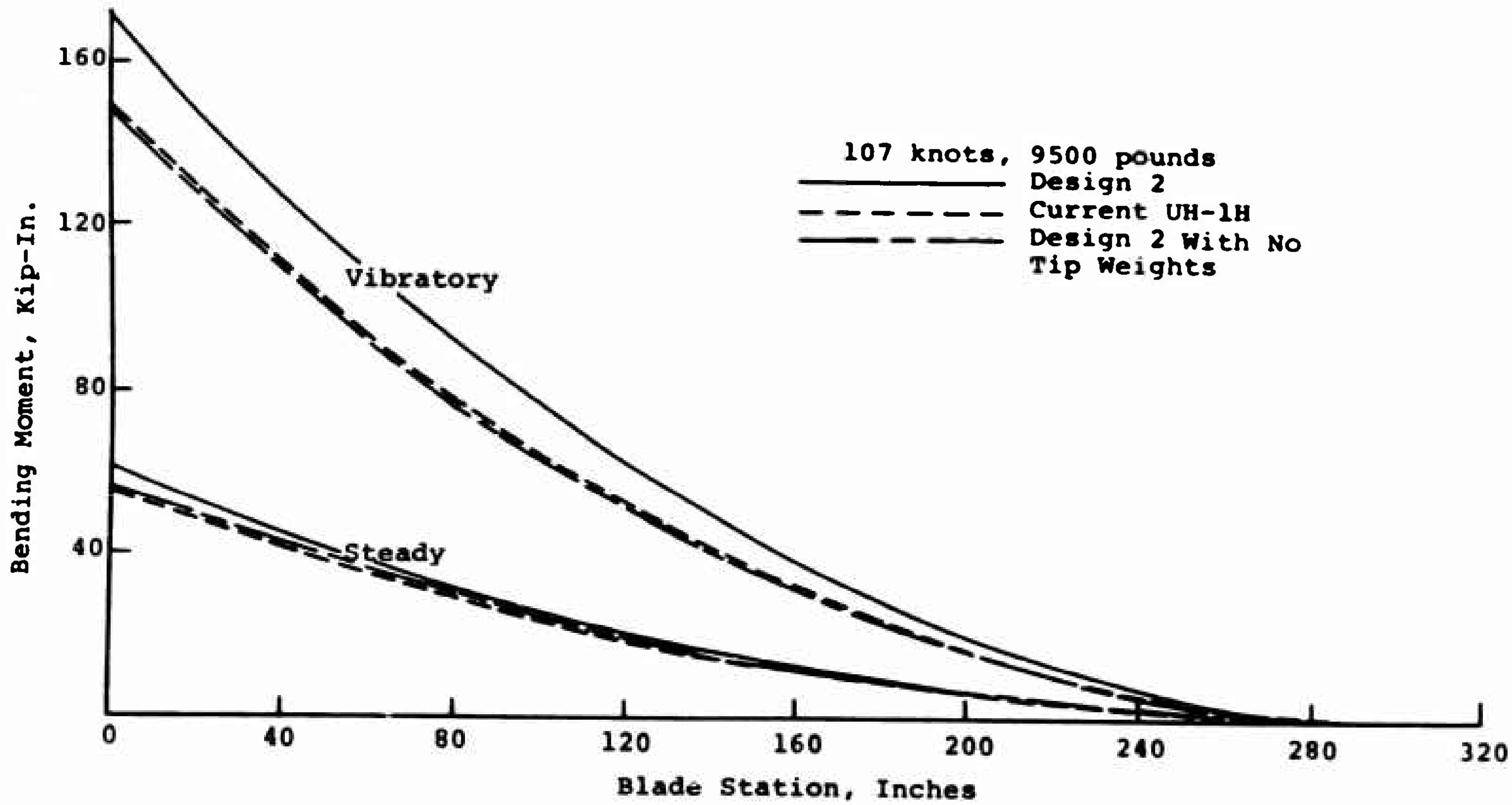

Figure 41. Flight Loading, In-Plane, Design 2.

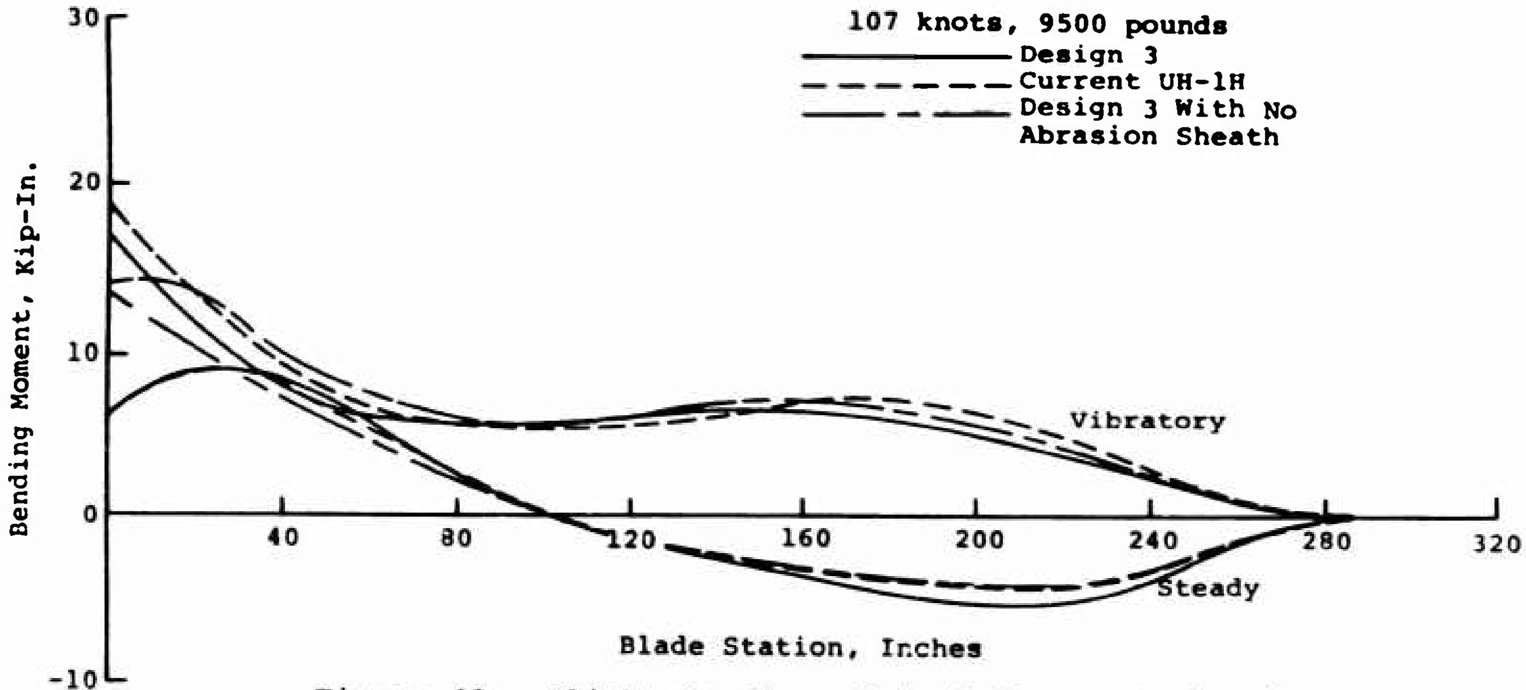

Figure 42. Flight Loading, Out-of-Plane, Design 3.

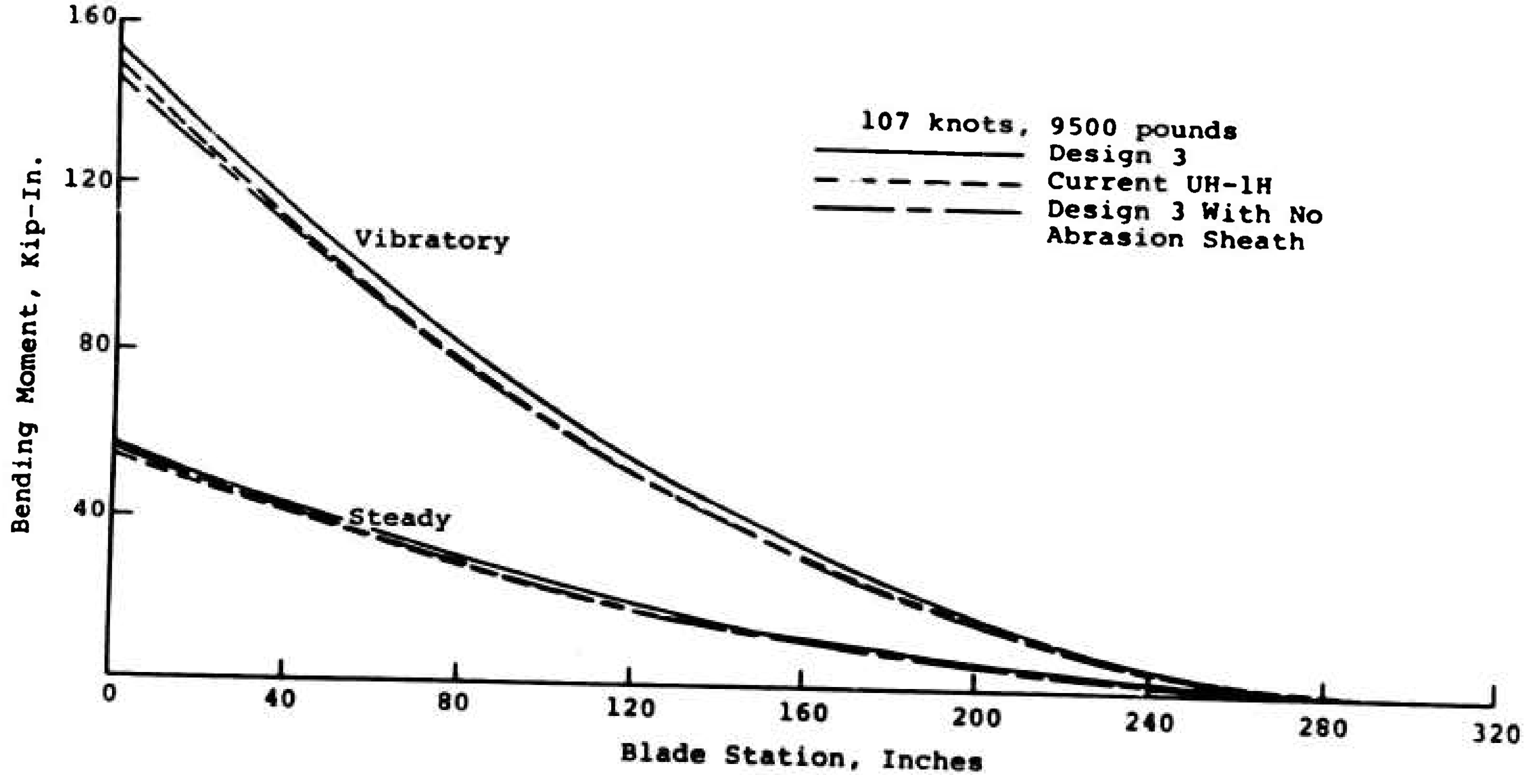

Figure 43. Flight Loading, In-Plane, Design 3.

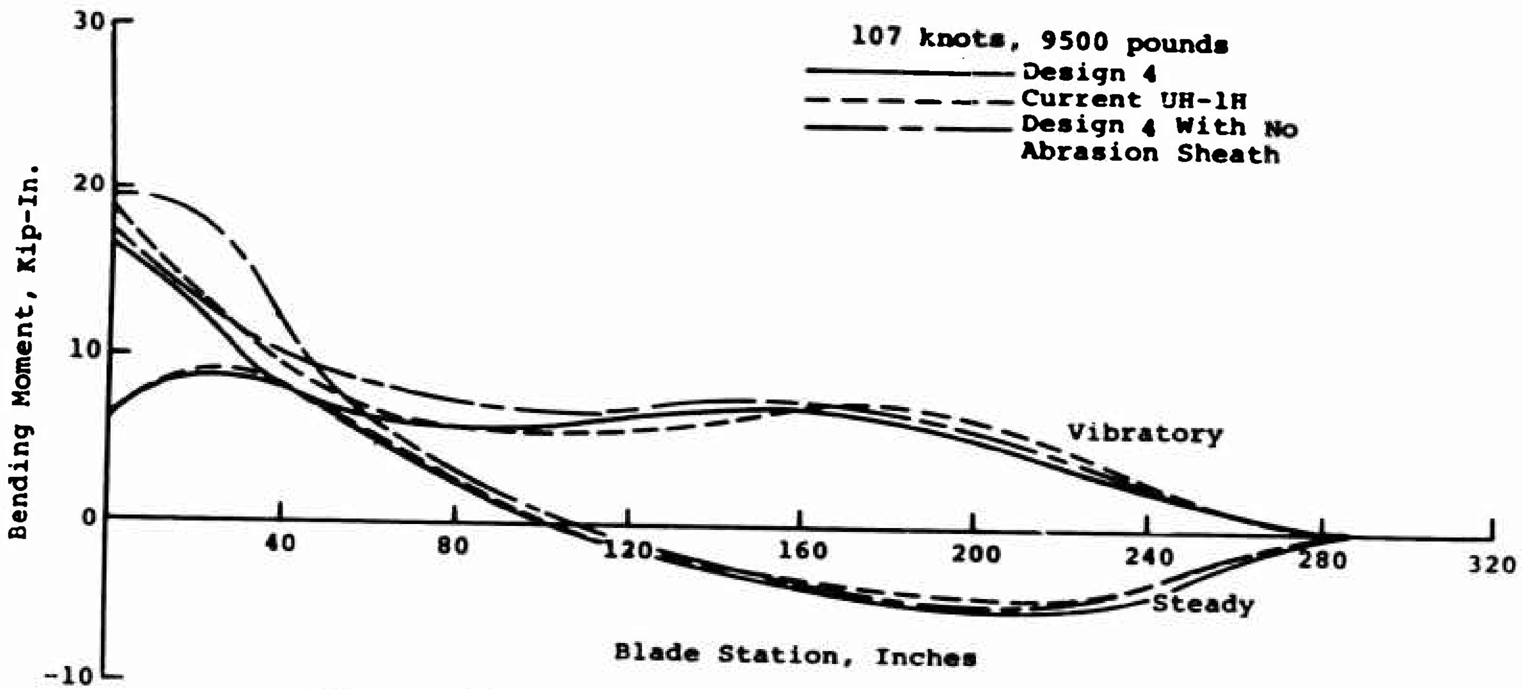

Figure 44. Flight Loading, Out-of-Plane, Design 4.

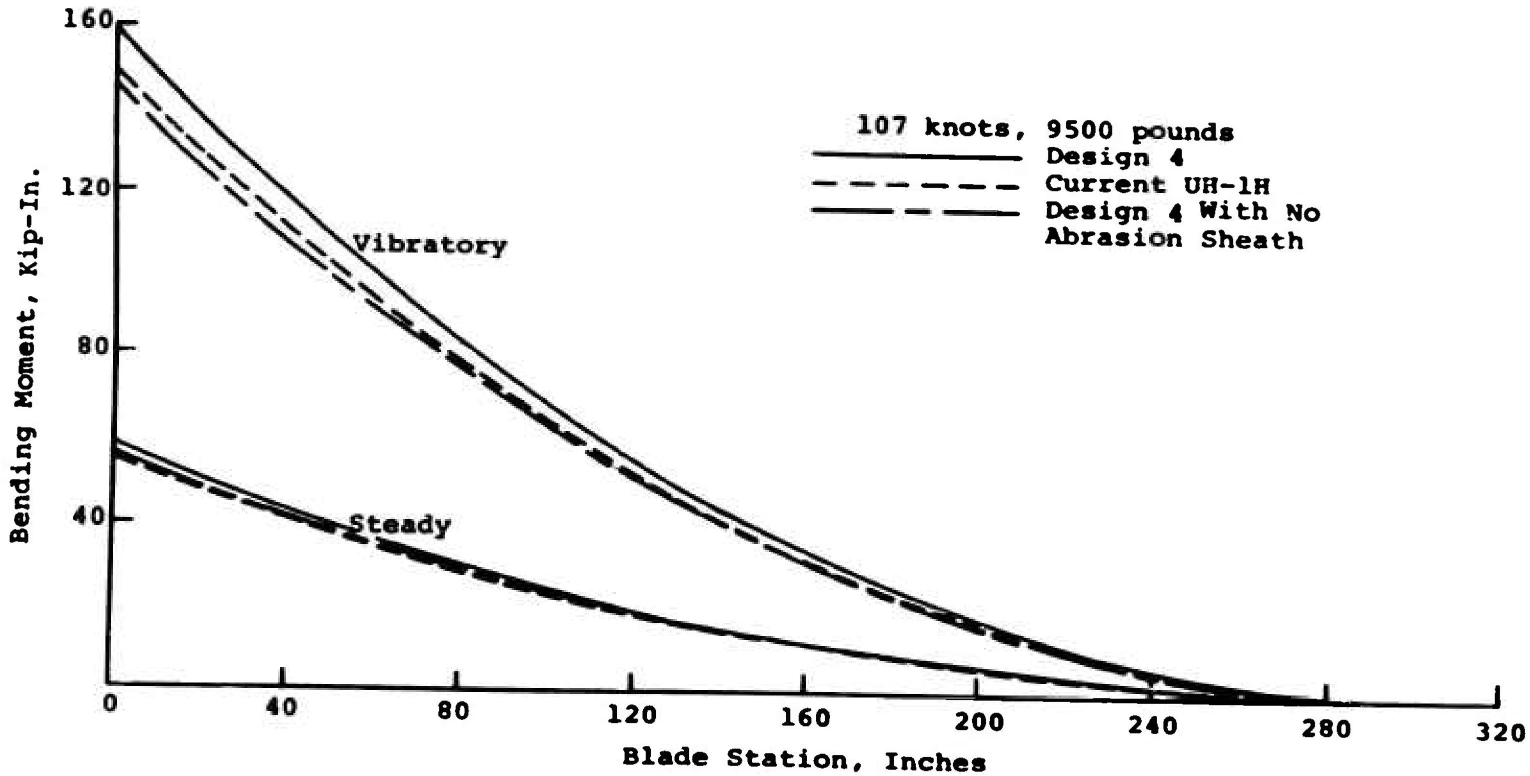

Figure 45. Flight Loading, In-Plane, Design 4.

STRESS ANALYSES

Stress analyses for the standard UH-1H main rotor blade and for the four expendable blade concepts, with and without added tip mass, were performed at Rotor Stations 82 and 210 and at significant intermediate stations. Stresses were obtained at the leading and trailing edges, at the maximum thickness station, and at corners or edges of the structural components.

The stresses were calculated for the combination of centrifugal force (Figures 26 through 29), centrifugal bending due to the offset of the centrifugal force vector from the structural neutral axis (Figures 26 through 29), and the in-plane and out-of-plane dynamic air load bending moments (Figures 38 through 45).

Margins of safety were determined, as fatigue margins, by comparing the calculated alternating stress with the allowable alternating stress. This allowable alternating stress was obtained from the endurance limit by a straight-line Goodman diagram reduction for the calculated steady stress. The analytical procedure is the same as that followed in Reference 1.

The following formulae were used to determine the stresses and margins of safety:

$$f = \frac{P_C . E}{\sum EA} - \frac{M_C . x . E}{\sum EI_{yy}} - \frac{M_y . x . E}{\sum EI_{yy}} + \frac{M_x . y . E}{\sum EI_{xx}} \qquad (1)$$

where f = stress at a point on the blade cross section, psi

P_C = centrifugal force, pounds, tension positive

E = Young's modulus of material, psi

$\sum EA$ = total section axial stiffness, pounds

M_C = bending moment due to centrifugal force, in-plane only, lb-in., positive for leading edge in tension

x = perpendicular distance from stress point to major (vertical) structural principal axis, inches, positive aft

ΣEI_{yy} = total section in-plane bending stiffness, lb-in.^{2}

M_y = in-plane bending moment due to air loads, lb-in., positive for leading edge in tension

M_x = out-of-plane bending moment due to air loads, lb-in., positive for lower surface in tension

y = perpendicular distance from stress point to minor structural principal axis (chord line), inches, positive up

ΣEI_{xx} = total section flapwise bending stiffness, lb-in.^{2}

Note: The fourth term of equation (1), containing the product $M_x.y$, is assumed to be always positive because of the chord line symmetry of the blade section. This avoids the necessity to specify upper and lower stress points.

$$F_A = F_E \left(1 - \frac{f_s}{F_{tu}}\right) \qquad (2)$$

where F_A = allowable alternating stress, psi

F_E = endurance limit of material at zero steady stress, psi

f_s = calculated steady component of stress, psi

F_{tu} = ultimate tensile strength of material, psi

$$M = \frac{F_A}{f_a} - 1 \qquad (3)$$

where M = margin of safety

f_a = calculated alternating component of stress, psi

The material properties used in the stress analysis and in the calculation of the section properties are given in Table III.

The results of the stress analysis are summarized in Table IV.

TABLE III. MATERIAL PROPERTIES

Material		Modulus of Elasticity $E \times 10^{-6}$ (psi)	Modulus of Rigidity $G \times 10^{-6}$ (psi)	Density (lb/in.^{3})	Ultimate Tensile Strength F_{tu} (psi)	Endurance Limit F_E (psi)
Aluminum, 2024-T3	(1)	10.5	4.0	.101	65,000	6,000
Aluminum, 6061-T6	(1)	10.0	3.8	.100	38,000	6,000
Stainless Steel, AISI 301	(1)	27.0	12.0	.286	125,000	18,000
Glass Fiber Reinforced Plastic, 2 Ply, $\pm$ 45°	(1)	3.863	1.56	.064	13,000	4,000
G.F.R.P., 3 Ply, $\pm$ 45°/0°/-45°	(2)	4.475	1.17	.064	34,000	4,000
G.F.R.P., Unidirectional, 0°	(1)	5.70	.40	.064	75,000	4,000
Cobalt Alloy, Haynes Stellite 6B	(3)	30.4		.303		

References: (1) Ref. 1, Table XII.
(2) Interpolated from Ref. 1 data.
(3) Manufacturers' data. Other properties not critical.

TABLE IV. BASIC STRESS ANALYSIS SUMMARY

Configuration	Station (inch)	Component	Coordinates (inch) X*	Coordinates (inch) Y**	Fatigue Stress (psi)	Margin of Safety
Current UH-1D/H	82	Spline	21.000	.027	7,385 ± 4,771	+ .114
		Skin	20.690	.070	7,521 ± 4,761	+ .114
		Spar	.677	.542	14,948 ± 2,759	+ .674
		Nose Weight	.020	0	14,786 ± 1,925	+ 1.409
		Abrasion Strip	0	0	38,039 ± 4,966	+ 1.523
	210	Spline	21.000	.027	12,507 ± 2,673	+ .814
		Skin	6.300	1.260	12,177 ± 2,862	+ .704
		Spar	.677	.542	10,332 ± 1,603	+ 2.148
		Nose Weight	.020	0	13,506 ± 809	+ 4.528
		Abrasion Strip	0	0	24,304 ± 1,611	+ 8.006
Design 1 (without abrasion sheath)	82	Spline	21.000	.027	5,452 ± 5,158	- .004
		Spline	20.700	.040	5,557 ± 5,080	+ .008
		Skin	20.700	.040	5,834 ± 5,334	+ .024
		Skin	6.500	1.240	11,438 ± 2,537	+ .949
		Spar	5.040	1.260	11,375 ± 2,404	+ .749
		Spar	0	0	12,163 ± 1,904	+ 1.143
	160	Spline	21.000	.027	6,982 ± 3,810	+ .286
		Spline	20.700	.040	7,006 ± 3,767	+ .299
		Skin	20.700	.040	7,356 ± 3,956	+ .345
		Skin	6.500	1.240	9,085 ± 3,089	+ .671
		Spar	5.040	1.260	8,732 ± 2,647	+ .746
		Spar	0	0	7,856 ± 1,068	+ 3.457
	210	Spline	21.000	.027	8,589 ± 2,639	+ .760
		Spline	20.700	.040	8,548 ± 2,611	+ .781
		Skin	20.700	.040	8,975 ± 2,741	+ .887
		Skin	6.500	1.240	7,821 ± 2,181	+ 1.420
		Spar	5.040	1.260	7,184 ± 1,882	+ 1.586
		Spar	0	0	4,326 ± 608	+ 7.739

TABLE IV - Continued

Configuration	Station (inch)	Component	Coordinates (inch) X*	Coordinates (inch) Y**	Fatigue Stress (psi)	Margin of Safety
Design 1 (with abrasion sheath)	82	Spline	21.000	.027	5,019 ± 5,512	- .055
		Spline	20.700	.040	5,142 ± 5,425	- .044
		Skin	20.700	.040	5,399 ± 5,696	- .034
		Skin	6.500	1.240	11,927 ± 2,363	+ 1.073
		Spar	5.040	1.260	11,935 ± 2,232	+ .844
		Spar	0	0	13,098 ± 2,037	+ .930
	160	Spline	21.000	.027	6,342 ± 3,997	+ .251
		Spline	20.700	.040	6,391 ± 3,949	+ .264
		Skin	20.700	.040	6,711 ± 4,147	+ .297
		Skin	6.500	1.240	9,852 ± 2,918	+ .744
		Spar	5.040	1.260	9,580 ± 2,464	+ .821
		Spar	0	0	8,847 ± 1,122	+ 3.101
	210	Spline	21.000	.027	7,275 ± 2,929	+ .656
		Spline	20.700	.040	7,268 ± 2,894	+ .677
		Skin	20.700	.040	7,632 ± 3,039	+ .743
		Skin	6.500	1.240	8,177 ± 2,066	+ 1.539
		Spar	5.040	1.260	7,692 ± 1,744	+ 1.745
		Spar	0	0	5,450 ± 677	+ 6.591
Design 2 (without tip weights)	82	Spline	21.000	.027	3,426 ± 3,305	+ .155
		Spar Aft Web	8.870	1.000	28,992 ± 7,929	+ .744
		Skin	5.040	1.260	5,454 ± 1,005	+ 2.342
		Spar Nose Skin	5.040	1.260	32,909 ± 6,063	+ 1.187
		Spar Nose Skin	0	0	34,241 ± 5,422	+ 1.410
	120	Spline	21.000	.027	4,731 ± 3,112	+ .204
		Spar Aft Web	8.870	1.000	27,080 ± 9,398	+ .500
		Skin	5.040	1.260	4,730 ± 1,233	+ 1.792
		Skin	3.400	1.210	4,825 ± 1,341	+ 1.560
		Spar Nose Skin	3.400	1.210	29,111 ± 8,091	+ .707
		Spar Nose Skin	0	0	29,938 ± 4,253	+ 2.219

TABLE IV - Continued						
Configuration	Station (inch)	Component	Coordinates (inch) X*	Y**	Fatigue Stress (psi)	Margin of Safety
Design 2 (without tip weights)	160	Spline	21.000	.027	6,231 ± 2,910	+ .261
		Spar Aft Web	8.870	1.000	30,307 ± 8,933	+ .527
		Skin	5.040	1.260	5,040 ± 1,185	+ 1.875
		Skin	3.400	1.210	4,962 ± 1,210	+ 1.824
		Spar Nose Skin	3.400	1.210	29,935 ± 7,298	+ .876
		Spar Nose Skin	0	0	25,440 ± 3,688	+ 2.887
	210	Spline	21.000	.027	6,440 ± 1,691	+ 1.163
		Spar Aft Web	8.870	1.000	25,181 ± 5,477	+ 1.219
		Skin	5.040	1.260	3,867 ± 961	+ 2.687
		Skin	3.400	1.210	3,639 ± 837	+ 3.268
		Spar Nose Skin	3.400	1.210	21,957 ± 5,049	+ 1.939
		Spar Nose Skin	0	0	15,127 ± 1,644	+ 8.624
Design 2 (with tip weights)	82	Spline	21.000	.027	3,662 ± 3,923	- .030
		Spar Aft Web	8.870	1.000	29,539 ± 7,965	+ .726
		Skin	5.040	1.260	5,521 ± 889	+ 2.768
		Spar Nose Skin	5.040	1.260	33,311 ± 5,364	+ 1.461
		Spar Nose Skin	0	0	35,654 ± 6,450	+ .995
	120	Spline	21.000	.027	5,277 ± 3,622	+ .027
		Spar Aft Web	8.870	1.000	29,701 ± 9,527	+ .440
		Skin	5.040	1.260	5,159 ± 1,139	+ 1.979
		Skin	3.400	1.210	5,228 ± 1,276	+ 1.652
		Spar Nose Skin	3.400	1.210	31,544 ± 7,700	+ .748
		Spar Nose Skin	0	0	31,055 ± 4,960	+ 1.727
	160	Spline	21.000	.027	6,231 ± 2,909	+ .261
		Spar Aft Web	8.870	1.000	30,307 ± 8,933	+ .527
		Skin	5.040	1.260	5,040 ± 1,185	+ 1.875
		Skin	3.400	1.210	4,962 ± 1,210	+ 1.824
		Spar Nose Skin	3.400	1.210	29,935 ± 7,298	+ .876
		Spar Nose Skin	0	0	25,440 ± 3,688	+ 2.887

TABLE IV - Continued

Configuration	Station (inch)	Component	Coordinates (inch) X*	Coordinates (inch) Y**	Fatigue Stress (psi)	Margin of Safety
Design 2 (with tip weights)	210	Spline	21.000	.027	7,601 ± 1,953	+ .841
		Spar Aft Web	8.870	1.000	29,279 ± 6,203	+ 1.222
		Skin	5.040	1.260	4,463 ± 842	+ 3.128
		Skin	3.400	1.210	4,167 ± 708	+ 3.956
		Spar Nose Skin	3.400	1.210	25,142 ± 4,273	+ 2.365
		Spar Nose Skin	0	0	16,099 ± 1,906	+ 7.227
Design 3 (without abrasion sheath)	82	Spline	21.000	.027	6,381 ± 4,992	+ .000
		Skin	20.630	.060	2,513 ± 1,906	+ .693
		Skin	5.500	1.260	4,444 ± 926	+ 1.842
		Spar	6.300	1.220	11,259 ± 2,477	+ .704
		Spar	5.040	1.260	11,625 ± 2,546	+ .636
		Spar	0	0	11,894 ± 1,824	+ 1.260
	160	Spline	21.000	.027	7,862 ± 3,213	+ .481
		Skin	20.630	.060	3,052 ± 1,240	+ 1.469
		Skin	5.500	1.260	3,599 ± 1,052	+ 1.748
		Spar	6.300	1.220	9,265 ± 2,798	+ .622
		Spar	5.040	1.260	9,326 ± 2,635	+ .718
		Spar	0	0	8,203 ± 916	+ 4.139
	210	Spline	21.000	.027	8,557 ± 2,040	+ 1.279
		Skin	20.630	.060	3,299 ± 792	+ 2.769
		Skin	5.500	1.260	2,970 ± 867	+ 2.560
		Spar	6.300	1.220	7,765 ± 2,273	+ 1.101
		Spar	5.040	1.260	7,617 ± 2,190	+ 1.191
		Spar	0	0	5,190 ± 487	+ 9.640
Design 3 (with abrasion sheath)	82	Spline	21.000	.027	5,954 ± 5,342	- .053
		Skin	20.630	.060	2,356 ± 2,036	+ .608
		Skin	5.500	1.260	4,612 ± 869	+ 1.969
		Spar	6.300	1.220	11,644 ± 2,346	+ .774
		Spar	5.040	1.260	12,091 ± 2,409	+ .698
		Spar	0	0	12,939 ± 1,954	+ 1.025

TABLE IV - Continued

Configuration	Station (inch)	Component	Coordinates (inch) X*	Coordinates (inch) Y**	Fatigue Stress (psi)	Margin of Safety
Design 3 (with abrasion sheath)	160	Spline	21.000	.027	7,448 ± 3,428	+ .407
		Skin	20.630	.060	2,904 ± 1,320	+ 1.353
		Skin	5,500	1.260	3,944 ± 1,042	+ 1.675
		Spar	6.300	1.220	10,093 ± 2,782	+ .584
		Spar	5.040	1.260	10,251 ± 2,601	+ .684
		Spar	0	0	9,303 ± 978	+ 3.632
	210	Spline	21.000	.027	9,112 ± 1,990	+ 1.293
		Skin	20.630	.060	3,519 ± 769	+ 2.792
		Skin	5.500	1.260	3,387 ± 719	+ 3.111
		Spar	6.300	1.220	8,824 ± 1,901	+ 1.423
		Spar	5.040	1.260	8,700 ± 1,809	+ 1.557
		Spar	0	0	5,945 ± 477	+ 9.618
Design 4 (without abrasion sheath)	82	Aft Section	21.000	.027	6,518 ± 5,501	- .096
		Spar	7.150	1.218	11,363 ± 3,295	+ .277
		Aft Section	6.300	1.260	11,633 ± 3,092	+ .347
		Spar and Aft Section	5.500	1.244	11,840 ± 2,780	+ .486
		Spar	0	0	12,292 ± 1,828	+ 1.220
	96.4	Aft Section	21.000	.027	7,937 ± 6,962	- .318
		Spar	7.150	1.218	10,612 ± 3,555	+ .216
		Aft Section	6.300	1.260	10,763 ± 3,282	+ .311
		Spar and Aft Section	5.500	1.244	10,881 ± 2,908	+ .472
		Spar	0	0	11,207 ± 2,019	+ 1.096
	160	Aft Section	21.000	.027	6,946 ± 3,453	+ .420
		Spar	7.150	1.218	9,242 ± 3.260	+ .393
		Aft Section	6.300	1.260	9,350 ± 3,178	+ .423
		Spar and Aft Section	5.500	1.244	9,394 ± 2,975	+ .518
		Spar	0	0	8,519 ± 992	+ 3.694

TABLE IV - Continued

Configuration	Station (inch)	Component	Coordinates (inch) X*	Y**	Fatigue Stress (psi)	Margin of Safety
Design 4 (without abrasion sheath)	210	Aft Section	21.000	.027	5,264 ± 1,434	+ 2.606
		Spar	7.150	1.218	7,479 ± 2,107	+ 1.287
		Aft Section	6.300	1.260	7,570 ± 2,100	+ 1.288
		Spar/Aft Section	5.500	1.244	7,576 ± 2,006	+ 1.394
		Spar	0	0	5,986 ± 407	>10
Design 4 (with abrasion sheath)	82	Aft Section	21.000	.027	6,191 ± 6,095	- .176
		Spar	7.150	1.218	11,842 ± 2,845	+ .452
		Aft Section	6.300	1.260	12,166 ± 2,591	+ .574
		Spar/Aft Section	5.500	1.244	12,430 ± 2,255	+ .790
		Spar	0	0	13,413 ± 2,031	+ .911
	96.4	Aft Section	21.000	.027	6,399 ± 7,461	- .331
		Spar	7.150	1.218	10,740 ± 3,220	+ .337
		Aft Section	6.300	1.260	11,000 ± 2,906	+ .467
		Spar/Aft Section	5.500	1.244	11,232 ± 2,513	+ .682
		Spar	0	0	12,588 ± 2,167	+ .851
	160	Aft Section	21.000	.027	6,610 ± 3,609	+ .373
		Spar	7.150	1.218	10,084 ± 2,986	+ .476
		Aft Section	6.300	1.260	10,260 ± 2,885	+ .518
		Spar/Aft Section	5.500	1.244	10,359 ± 2,677	+ .630
		Spar	0	0	9,688 ± 1,039	+ 3.302
	210	Aft Section	21.000	.027	4,603 ± 1,358	+ 2.885
		Spar	7.150	1.218	8,017 ± 1,873	+ 1.528
		Aft Section	6.300	1.260	8,175 ± 1,862	+ 1.530
		Spar/Aft Section	5.500	1.244	8,232 ± 1,775	+ 1.649
		Spar	0	0	6,750 ± 386	> 10

* X is measured from the leading edge parallel to the chord plane.
** Y is measured from the chord plane and perpendicular to it.

DISCUSSION OF DYNAMIC AND STRESS ANALYSES

The dynamic bending moment distributions and natural frequencies are not significantly different from those of the current UH-1H main rotor blade for any of the four concepts studied, as can be seen from Figures 34 through 45. The result of this lack of significant change is demonstrated in the stress analysis. For all four designs, the margins of safety calculated on the same basis as those of the current blade are everywhere positive, except in the trailing edge near the root of Designs 1 and 4, and Designs 2 and 3 after the addition of the tip weights and abrasion strip. Except in Design 4, the negative margins are less than 6% and can be corrected, if necessary, during detail design by the addition of material to the trailing-edge spline near the root. This will have the dual effect of strengthening the blade in in-plane bending, and of slightly increasing the in-plane natural frequency and reducing the first harmonic amplification factor, and consequently the bending moment. The increase in the spline can be confined to the sections near the root, and will not upset the blade balance.

Design 4, however, is seriously below strength, and because of the constant section design, any increase in material at the trailing edge at the root must be continued outboard with the accompanying difficulty in chordwise balance. Extending the aft doubler fingers further outboard becomes increasingly impractical from a manufacturing standpoint, and thickening the trailing edge will have adverse aerodynamic effects. Design 4, therefore, is impractical technically as well as due to manufacturing difficulty.

The aluminum alloy chosen for the spars of Designs 1 and 3 is 6061, which was selected for its extrudability. Its ultimate strength is considerably below the strengths of the harder alloys such as 2014, 2024, and 7075. However, in these applications, ultimate strength can be given up in favor of other qualities because it has no serious effect on either the design or the life of these rotor blades. The usual benefit which accrues from higher strength is a reduction in weight; but in Designs 1 and 3, the spar is used to balance the blade section, so that any reduction in spar weight would have to be replaced with added ballast. Reduction in the weight of the spar is further precluded by the minimum extrudable wall thickness, which was the thickness chosen, and which might even increase if one of the harder alloys were used.

The allowable life of the blades is affected primarily by the endurance limit of the material chosen, if the flight stresses are constant, and only secondarily by the ultimate strength as it affects the Goodman diagram. The endurance limits of all aluminum alloys in general use are about the same, at approximately 6,000 psi (see Table III). Since less than 5% of the current blades reach their allowable fatigue lives, this consideration is also of minor importance.

As a structural material, particularly in a fatigue environment, 6061 alloy has one significant advantage in its fracture toughness. The crack propagation rate of this alloy is appreciably slower than that of other structural aluminum alloys. Figure 46, redrawn from Figure 7 of Reference 6, graphically illustrates this characteristic. The hypotenuse of the triangle represents an ideal material where the loss of strength is in direct proportion to the loss of area due to cracking. The deviation from this line for each of the real alloys is the additional reduction in strength due to notch-sensitivity. Although the data from which this figure was plotted were generated some fifteen years ago, they represent valid experimental results in spite of the more sophisticated testing techniques and specimens in use since. More recent experience tends to confirm the fracture-toughness relationship between these alloys. The current UH-1H blade uses 2014-T6 or 2024-T4 aluminum alloy for the extruded spar, so that fracture toughness would improve in the expendable concepts.

Comparison of the computed natural frequencies, flight bending moments, and margins of safety of the expendable blade concepts with those computed for the current blade shows that, with the exception of Design 4, allowable fatigue lives close to 2500 hours as specified for the current blade can be achieved. Therefore, a fatigue life of 2500 hours is used in the life-cycle cost analysis.

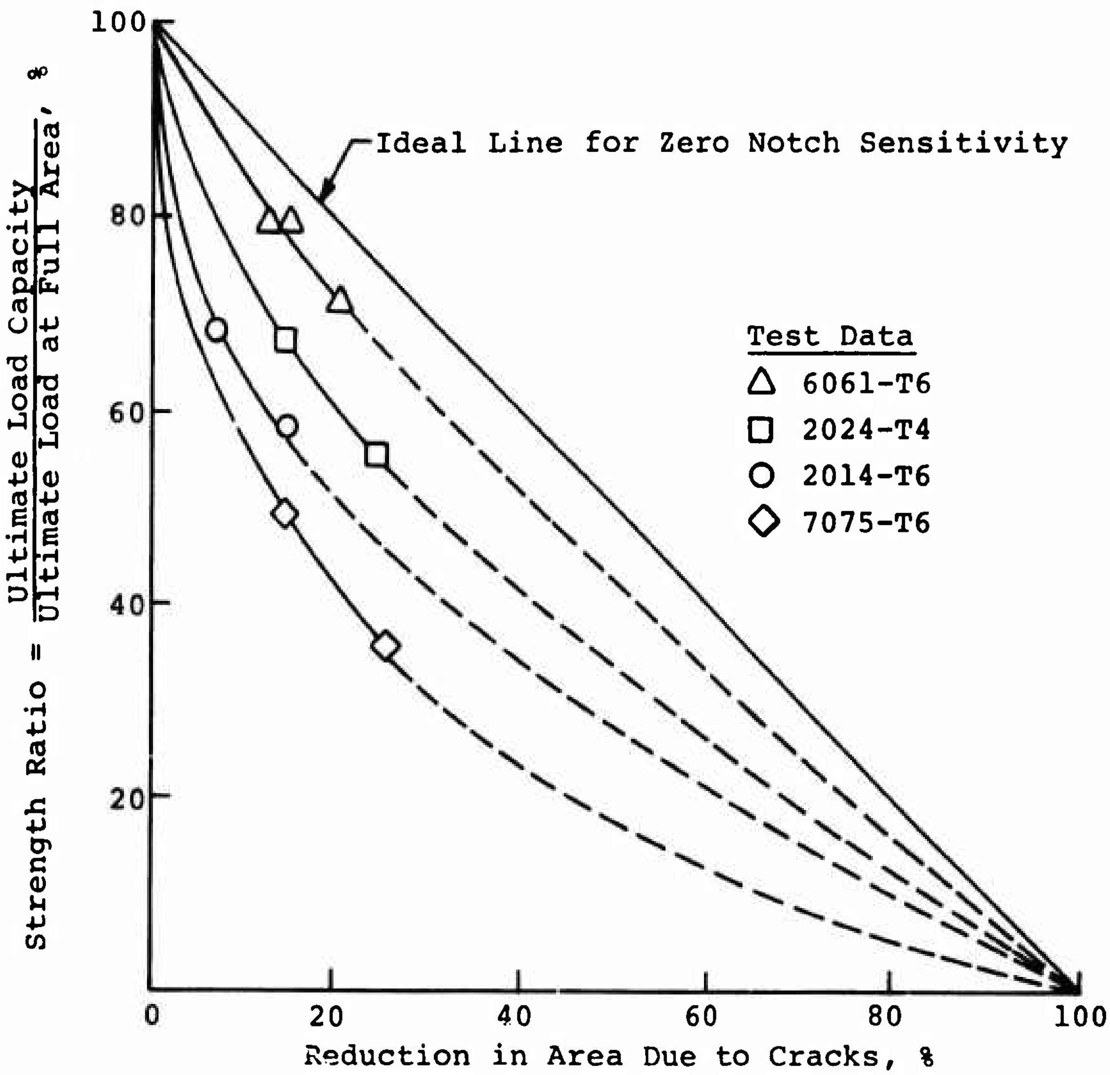

Figure 46. Fracture Toughness of Aluminum Alloys.

RELIABILITY ANALYSIS

The reliability of three of the candidate design concepts was studied and compared with that of the current UH-1D/H main rotor blade. Because of the manufacturing problems described above, Design 4 was not pursued into the reliability phase of the study.

Attention was given during the reliability analysis to combinations of materials, and construction details, which could be expected to have slow rates of crack propagation, and to design details which would increase resistance to corrosion. Corrosion is more important to the maintenance of an expendable blade because there is less opportunity to arrest corrosion, especially if the intermediate maintenance level is physically far removed from the organizational level.

As background for the reliability analysis, a UH-2 main rotor blade with glass-fiber-reinforced plastic skins which had been greatly repaired at military depots was examined. This examination provided the experience on which the failure modes and effects analysis (FMEA) was based for the skins of Designs 2 and 3. From this, and general service experience for the current UH-1H blade, FMEA's to the piece-part level were prepared for the current UH-1H blade and candidate Designs 1, 2, and 3. Parts were omitted from the analysis whose modification, if any were needed, from the present UH-1H design would not affect the rate of removal or scrap. The failure modes and effects analyses are presented in Appendix I.

The descriptions of failures or damage quoted in the "Mode of Failure" columns of Table XIV in Appendix I are those listed in Table H-I of Reference 2. The frequencies of removal from this table were ratioed to conform with those given in Appendix IV (Attachment F-1 of Reference 5) for inherent and external causes. The total frequency is thus the reciprocal of (.292/547 and .708/400), or 434 hours. Refinements to Table XIV resulted in a value of 442 hours, but the accuracy remained close enough that correction was not warranted. These data referred to MTR values, but examination of Reference 2, after completion of Table XIV, indicated that an MTBR of 1063 hours (Tables XIII and D-VII of Reference 2) distributed 24.5:75.5 between inherent and external causes (M & R data, Table XIII, Reference 2) is more realistic. The remainder of the reliability, maintainability, and cost analyses is based on these latter failure rates and causes.

The removal rates for specific failure modes or damage to the current UH-1H obtained as above were apportioned by engineering judgment to piece parts of the blade, if defects in more than one location could lead to the given failure report coding. These removal rates were considered failure rates and listed in the first column of the FMEA's (Appendix I). They were modified to suit candidate configurations according to vulnerable area, strength ratios, durability, aerodynamics, and anticipated attitudes of future field personnel using expendable blades. The damage descriptions utilized are those defined as follows:

Dent - As might be caused by bullet, foreign objects, mishandling, or tools.

Puncture - A hole through one surface of the part being analyzed.

Battle Damage - A projectile through the blade.

Foreign Object - Damage caused by collision with small or large objects such as trees, other aircraft, poles, or objects in the air.

General Reliability Analysis Conclusions

A summary of failure rates for the four configurations is shown in Table V. The predicted failure rates for the totals of inherent causes are not drastically different from one configuration to the other; but in the case of the external damage total failure rates, there are substantial differences in vulnerability.

Fiberglass skin blades are less likely to develop large voids under the skin in the field. Voids in manufacturing are detectable by translucence. A strictly expendable maintenance concept for a blade with fiberglass skin is considered to be less efficient than a concept which allows nonextensive repairs at the user level, because repairs made to fiberglass skin are quite reliable. Minor repairs prevent propagation of damage to the extent of adversely affecting flight.

An aluminum skin is prone to fatigue failure caused by notch effect at a point where the skin was damaged during installation or use. A strictly expendable concept for an aluminum skin blade, however, is considered safer than allowing repairs at user level, because patches on aluminum skin should be inspected daily for cracks.

TABLE V. SUMMARY OF FAILURE RATES

Mode	Failures Per 10^6 Blade Hours			
	Current UH-1H	Design 1	Design 2	Design 3
Inherent Failure	230.4	181.9	145.8	153.0
External Damage	710.3	754.4	633.8	942.6
Total Fail Rate	940.7	936.3	779.6	1,095.6
MTBR (Blade Hr)	1,063.0	1,068.0	1,282.7	912.7

For any design, a strictly expendable concept involves the hazard that organizational level personnel may try to get too many flights out of a marginally defective blade when the only alternative is scrappage. Minor repairs at user level facilities allow safe operation until replacements can be obtained, as well as reducing scrap costs.

Because of the difficulty of detecting damage due to overspeed or overload, the safety of future helicopters in this category would be enhanced by the use of overspeed-recording indicators and indicators for recording torque and time.

All of the candidate blades analyzed use cores with straight sides. This will result in less defects involving voids being found in the field than experienced to date with either the current UH-1 or current H-2 main rotor blades. The simpler geometry of these cores allows manufacturing with more uniformity of bonding between core and skin. Thus, in field use, there are less weak spots which can fatigue early in the blade life to become larger voids and adversely affect performance. Two of the candidate blades have leading edges which lack the protection from abuse that the full length steel sheath provides in the current UH-1. The possibility that such abuse might cause notch effects and fatigue failures in flight is something that would be investigated more fully during a prototype phase contract.

<u>Reliability Analysis Conclusion on Design 1</u>

This design involves less probability of voids and other bonding defects occurring in the field than the current UH-1H design. In mid-span there are fewer parts that require bonding and all are aluminum; therefore, the bonds are not stressed by differences in thermal expansion coefficients. The heavy leading-edge spars of Designs 1 and 3 will absorb impact that would loosen the nose block bonds of the current UH-1H design. This design involves a straight-sided core which is easier to carve and handle in manufacturing than the contoured core of the current UH-1H blade. Therefore, voids in manufacturing and resulting increased voids in field use are expected to be less than with the current UH-1H blade. The skin material, however, is the same and the core is similar. Therefore, the ability to be repaired at local intermediate shops, after damage that is past the limits allowed in the skin without any repair, is no better in this candidate blade than in the current UH-1H blade. Specifically, any skin patches applied inboard of Station 240 should be inspected daily for cracks. The spar is extruded in a shape which inhibits vertical movement of the core after failure of the core-to-spar bond. Thus, the probability of skin fatigue cracks at the edge of the spar is reduced. Degradation from galvanic corrosion after failure of adhesive or coatings is minimal in this design and in Design 3, as the number of nonaluminum parts is limited.

Reliability Analysis Conclusion on Design 2

The FMEA on this design is based partly on developmental lab results in steel spar blades for helicopters now in use. This design involves a higher risk of bond failure causing catastrophic results than any of the other candidates. This configuration also requires seven pieces to be bonded at mid-span in the forward portion of the blade. Bond failure of one piece, the stiffener, would only degrade the appearance of the blade on the ground.

The strength of the spar depends entirely on the strength of the bonds, and inspection methods are limited to X-ray, ultrasonic, or tapping. There is no cobalt alloy erosion sheath on this blade, but erosion is not expected to be as severe as had been experienced using steel sheaths due to the stiffness of the nose skin itself. A thin sheath vibrated by the wet airstream will erode faster than a thick nose skin of erosion-resistant material right through. The heavy skin at the aft end of the spar assembly will resist cracking and failure of the core-to-spar assembly bond.

None of the materials in the aft section are corrodible. The thick aft skin over the shear web provides good protection for this portion of the spar against glancing bullets and foreign object damage. Damage would propagate more slowly in the unidirectional fiberglass spline than in the spline of any of the other designs considered.

Reliability Analysis Conclusion on Design 3

The skin and core of this design are only lightly loaded and may absorb considerable damage without reducing the stiffness of the blade. In the case of minor damage to the skin or core such as deep scratches or nicks, or punctures which do not extend deep enough to degrade the shear web, repairs could be made using only adhesives. However, in the case of projectiles through the shear web, the blade would need to be scrapped. After a core-to-spar bond failure, the shear-web-to-core bond restricts core movement. Thus the fatigue life of the skin at the aft edge of the spar is extended.

The heavy all-aluminum spar is wider than the current UH-1H blade and, therefore, would be hit by projectiles more frequently. The 6061 aluminum alloy of the Design 3 spar, however, does not allow crack propagation as readily as the box beam of the current UH-1H blade. Furthermore, the heavy leading edge of the Design 3 concept spar could absorb a stronger shock without cracking than the leading edge of the current UH-1H blade. The heavy leading edge of the Design 3 spar is not expected to save many blades from being scrapped due to collisions with foreign objects as compared with the UH-1H, because there are limits on the depth of the damage in the Design 3 spar that can be polished out without causing stress concentration points which might lead to a fatigue failure in a future flight. The current UH-1H blade has a steel sheath which absorbs abuse without denting to extensive depths and can be polished down nearly through its thickness, as it is not a principal load-carrying member.

This concept should be freer of bond defects than any of the other concepts analyzed. First, there are less parts in mid-span bonded. Second, the parts that are bonded are more lightly loaded than in the other concepts. Third, the only thermal stresses on the bonds at mid-span are aluminum to skin.

Theoretically, the peel strength of the skin-to-core bond determines the probability of a tear propagating, not the strength of the skin. Fiberglass skin does not tear readily. There is, however, a lack of field experience with helicopter blade fiberglass skins as thin as .012 inch at manufacture. If this candidate design is chosen for a prototype program, it is recommended that tear propagation tests be conducted as the last portion of a whirl test.

MAINTAINABILITY ANALYSIS

A study of competitive blade designs within an expendable concept must include repair considerations for cases involving relatively minor damage. A maintainability analysis was performed to assess relative repairability and cost of repairs in terms of man-hours and materials. Also evaluated were equipment requirements and personnel skill levels needed to accomplish the work. The maintainability analysis was developed from the reliability effort which assigned damage types and rates to candidate blades.

The selected approach to maintainability analysis produced data in terms suitable for input to the cost model so that the cost of maintenance could be included in the total life cycle costs for each blade design; the basic data determined were repair probabilities, maintenance man-hours per flight-hour, mean aircraft downtime, and materials required to accomplish repair.

Scrap Versus Repair Decision

Apportionment of damage types and frequencies was accomplished for each of three candidate blade designs plus the current UH-1H blade via the failure modes and effects analysis performed by the Reliability Group. Individual damage types were then analyzed by the Maintainability Group and scrap or repair decisions were made using the following guidelines:

a. The only repairs permitted were those which could be accomplished using techniques, materials and personnel skills currently in use up to the level of intermediate maintenance.

b. All other damages, including those which would normally qualify for depot repair under current standards, were designated as scrap.

The scrap versus repair decisions are recorded in the last column of the failure modes and effects analysis sheets which appear as Tables XIV through XVII of Appendix I.

Maintenance Levels Assigned to Accomplish Repairs

Damages judged to be repairable were assigned to the maintenance level best suited to accomplish repair. Assignments are indicated in Tables XVIII through XXII of Appendix II. Organizational and intermediate level actions are indicated by entry of a repair time estimate in the respective repair time columns. A summary of the repair actions performed at the two levels of maintenance can be found for all blade configurations in Table VI. Maintenance level assignments were made using the following guidelines:

Organizational

a. May be accomplished by mechanic who normally inspects and maintains the helicopter.

b. Removal of blade not required.

c. Pneumatic tools or electrical equipment not required.

d. Relatively short aircraft downtime.

Intermediate

a. Requires mechanic trained in repair of rotor blades.

b. Removal of blade from helicopter significantly facilitates repair.

c. Availability of tools and power sources significantly facilitates repair.

d. Aircraft downtime to replace blade generally less than downtime to repair blade.

Table VI presents a summary of the dispositions of all damage as organizational level repair, intermediate level repair, or scrap, and includes the present UH-1H blade treated as expendable and as currently used.

Repair Procedures

Seven basic repair procedures were devised such that they could be used singly or in combination to accomplish repair of any damage incident previously judged repairable at organizational and intermediate maintenance levels. The procedures are included in Appendix III. It should be noted that the procedures are general in nature and not intended as instructions to maintenance personnel. They were used analytically in estimating times to accomplish repairs and to assure that adequate consideration was given to repair materials and equipment requirements. Specific combinations of procedures used and active repair times for each are given in Tables XVIII through XXII of Appendix II.

TABLE VI. SUMMARY OF DISPOSITIONS							
Config-uration	Failure Mode	Depot Scrap	Depot Repair	Field Scrap	Inter. Repair	Org. Repair	Total
		Part I. Failures Per 10^6 Blade Hours					
Current (Repair-able)	Inherent	74.5	35.1	100.2	20.6	0.0	230.4
	External	296.4	139.5	182.0	61.3	31.1	710.3
	Total	370.9	174.6	282.2	81.9	31.1	940.7
Current (Expend-able)	Inherent			209.8	20.6	0.0	230.4
	External			551.3	127.8	31.1	710.3
	Total			761.1	148.5	31.1	940.7
Design 1	Inherent			140.0	20.5	21.4	181.9
	External			573.5	130.9	50.0	754.4
	Total			713.5	151.4	71.5	936.3
Design 2	Inherent			67.4	76.4	2.0	145.8
	External			379.5	183.9	70.5	633.8
	Total			446.8	260.3	72.4	779.6
Design 3	Inherent			76.0	61.8	15.3	153.0
	External			509.6	363.0	70.1	942.6
	Total			585.5	424.7	85.3	1095.6
		Part II. % of Total Per Blade					
Current (Repair-able)	Inherent	7.9	3.7	10.7	2.2	0.0	24.5
	External	31.5	14.8	19.3	6.5	3.3	75.5
	Total	39.4	18.6	30.0	8.7	3.3	100.0
Current (Expend-able)	Inherent			22.3	2.2	0.0	24.5
	External			58.6	13.6	3.3	75.5
	Total			80.9	15.8	3.3	100.0
Design 1	Inherent			14.9	2.2	2.3	19.4
	External			61.2	14.0	5.3	80.6
	Total			76.2	16.2	7.6	100.0
Design 2	Inherent			8.6	9.8	0.3	18.7
	External			48.7	23.6	9.0	81.3
	Total			57.3	33.4	9.3	100.0
Design 3	Inherent			6.9	5.6	1.4	14.0
	External			46.5	33.1	6.4	86.0
	Total			53.4	38.8	7.8	100.0

Repair Kits

Availability of standard repair kits significantly reduces administrative and supply delays. Three kits are defined in Table XXIII of Appendix III. Each is related to a particular type of repair. Kit requirements for all organizational and intermediate level repairs of candidate blades are listed in Tables XVIII through XXII of Appendix II. A summary of kit use frequencies for each blade configuration is given in Table VII of this report. All kits have unlimited shelf life due to exclusion of adhesives and filler mixes. The adhesives must be stocked separately, and it is recommended that they be packaged in special two-compartment plastic pouches of a type already in use.

Equipment Requirements

Table XXIV, Appendix III, lists three groups of equipment used to accomplish repairs. The groups of equipment are numbered 1 through 3 and are directly related to the repair kits of the same numbers listed in Table XXIII of Appendix III. Thirteen items of equipment are listed, and all are in the Army supply system or commercially available except item 2, which is a specially designed inflatable rubber bladder and strap assembly which would be wrapped around a blade section being repaired to create bond pressure. The bladder design is simple and the item is inexpensive. A photograph of the bladder in use is shown in Figure 51 of Appendix III.

Skill Levels

Those repairs designated for organizational level maintenance are within the capabilities of "Helicopter Repairman - Single Rotor, Turbine Observation/Utility", MOS 67N20.

The repairs designated for intermediate level maintenance are within the capabilities of "Rotor and Propeller Repairman", MOS 68E20.

Blade Repairability

Table VI of this report summarizes the scrap/repair dispositions made on all damage apportioned to the three expendable blade designs plus the present UH-1H blade first treated as a repairable blade and then as an expendable blade. Table VI is in two parts. Part I lists absolute numbers of different types of dispositions projected for each of the blades per 10^6 blade operating hours. Part II lists each type of disposition in terms of percent of the total dispositions made for the respective blade.

TABLE VII. REPAIR KIT USE PER 10^6 FLIGHT HOURS

Kit No. and Type	Current Blade (Expendable)	Design 1	Design 2	Design 3
1. Blend Repair Kit	69.8	184.6	155.0	211.6
2. Fiberglass Patch Kit			631.9	983.8
3. Aluminum Patch Kit	346.7	343.2		

The total repairability of candidate blade configurations ranges from a low of 19.1% for the current UH-1H blade treated as expendable, to a high of 46.6% for Design 3. However, the latter blade design, as Part I of Table VI shows, was judged to be most susceptible to damage, with 1095.6 failures projected per 10^6 blade hours. The blade least susceptible to damage was Design 2 with 779.6 failures anticipated.

The higher repairability forecast for Design 3 is attributed to the use of fiberglass skins, which offer opportunity for larger patch repairs at the intermediate maintenance level. The most significant factor contributing to the low failure rate of Design 2 is its very durable and damage-resistant stainless steel spar.

Maintenance Times

Table VIII is a tabulation of system downtimes in calendar hours for each of the blade configurations. The methods used to calculate maintenance times are described below.

Mean-Time-to-Repair (MTTR)

The mean-time-to-repair is the arithmetic average of all repair times at each of the two maintenance levels. It is derived by summing the repair times and dividing by the number of repair actions. Only the actual blade repairs are included in the MTTR. The time for blade replacement in cases of scrap or higher level repair is omitted.

Maximum Repair Time (M_{max})

The maximum repair time is the 90th percentile repair time based on a lognormal distribution. The assumption of a lognormal distribution is based on statistical analyses of helicopter field maintenance records by the contractor which show this distribution yielding the best fit to similar repair actions. The density function for $X (X = \log_{10} t)$, normally distributed with mean $\bar{X}$ and standard deviation σ_x is:

$$f(X, \bar{X}, \sigma_x)\, dx \equiv \left(\frac{1}{\sigma_x \sqrt{2\pi}}\right) \exp\left[-\frac{(X - \bar{X})^2}{2\sigma_x^2}\right] dx$$

The method used to define the repair time distribution function has been developed by the contractor as part of a maintainability prediction model for aircraft systems and equipment. Equations developed from regression analysis of helicopter repair time data are used to predict the mean and variance of the log repair

TABLE VIII. MAINTENANCE TIME SUMMARY IN HOURS

Time Consideration	Current Blade (Expendable)	Design 1	Design 2	Design 3
Mean Time to Repair (MTTR)				
Organizational Level	.71	.92	.70	.91
Intermediate Level	1.60	1.62	2.32	2.41
Org. & Inter. Combined	1.45	1.39	1.99	2.16
Maximum Repair Time (M_{max})				
Organizational Level	1.30	1.78	1.28	1.75
Intermediate Level	3.42	3.47	5.20	5.42
Org. & Inter. Combined	3.05	2.90	4.39	4.81
Mean Maintenance Downtime ($\overline{DT}$)				
Org. Repair Actions only	3.76	3.83	3.34	4.14
All Organizational Actions*	3.75	3.76	3.72	3.78
Maintenance M-H/FH (MH/FH)**				
Organizational Level	.0165	.0155	.0127	.0178
Intermediate Level	.0006	.0006	.0015	.0024

* Includes non-repairable blade replacements
** Per single blade

times based on a known or calculated MTTR.

The least squares regression equation used to calculate the variance is

$$\sigma_x^2 = .0039 + .0990 \text{ MTTR}$$

where σ_x^2 = the variance of the logarithms of repair time. Available data indicates that this equation is reasonably valid for MTTR in the approximate range of 0.5 to 6.0 hours.

From the mean time to repair and the variance, the mean of the logarithms is calculated using

$$\bar{X} = \log \text{MTTR} - 1.1513\ \sigma_x^2$$

where $\bar{X}$ = the mean of the logarithms of repair time

The maximum repair time is then calculated from

$$M_{max} = \text{antilog}\ (\bar{X} + 1.282\ \sigma_x)$$

where M_{max} = the 90th percentile repair time

σ_x = the standard deviation of the logarithms of repair time

Mean-Maintenance-Downtime ($\overline{DT}$)

For organizational level repair actions, the helicopter will be down for the elapsed time required to effect the repair. Damage beyond repair or beyond organizational capability requires that the rotor blade be replaced and the damaged blade scrapped or sent to a higher level facility for repair. Aircraft downtime in these cases is the elapsed time required for a blade replacement. Based on an average of 7.5 man-hours per replacement (see Appendix IV) and an average crew of two men, the active maintenance downtime for a main rotor blade replacement is estimated at 3.75 hours. The mean-maintenance-downtime is then the arithmetic average of the organizational repair downtimes and the blade replacement downtimes. Downtime is the time during which maintenance is actually being performed. In the case of on-aircraft blade repair, time is added to account for adhesive and paint curing time where applicable. No allowances are made for administrative or supply delays.

Maintenance Man-Hours per Flight Hour (MH/FH)

In keeping with the computation of maintenance downtime, the man-hours at the organizational level are those required for on-aircraft blade repair or blade replacement when damage is beyond organizational capability. For both the organizational and intermediate level repair actions, man-hours are equivalent to repair time (one man per action). Unlike the downtime calculation, no time is allowed at organizational level for adhesive and paint curing, since no productive maintenance is performed during this time. An average of 7.5 man-hours is allocated for a blade replacement at organizational level.

Maintenance man-hours per flight-hour at the intermediate level are obtained by multiplying the MTTR per action by the number of actions projected per 10^6 flight hours, and then dividing by 10^6 hours.

Maintenance man-hours per flight-hour at the organizational level are obtained by summing the products of MTTR times number of repair actions plus 7.5 hours times number of replacements, and then dividing by 10^6 hours.

Balance and Track

Because the blades will be manufactured to be dynamically interchangeable with each other by a method which provides information for the complete mass characteristics of each blade, it is possible to make a chart relating each type of repair to the balance adjustment required to be made at the tip. In rare instances, insufficient adjustment may be available, due to manufacturing variations, and these blades should be scrapped rather than repaired. This combination of a specific repair with insufficient adjustment range will occur so rarely that the effect on the scrap rate will be insignificant. The time required to change the tip balance weights is included in the repair time, where balance adjustment is necessary.

Because all the allowable repairs are of relatively small extent, any effect on track due to changes in contour can be readily corrected by adjustment of the trim tab. The basic blade will suffer no change in actual or effective twist, so that adjustment of the pitch link is unlikely to be necessary. The amount of trim tab adjustment will be small, and the time required to correct the track is included in the time to install the blade.

COST ANALYSIS

Utilizing the cost model described earlier, main rotor blade life-cycle costs were generated for current UH-1D/H blades and the three expendable blade designs. Cost elements generated in this study are described herein, and those supplied by the Army are identified here as well as being included in Appendix IV.

Price of New Blades

With a given concept defined physically, a cost estimate to produce the blade was made, and the experience curve slope was established as shown in Figure 47. The adjusted candidate blade costs, based on mid-1971 rates, are shown in Table IX, along with the production cost estimate of the UH-1D/H blade. To the production cost are added the nonrecurring cost amortized over 10,000 blades, and profit. This price is considered the FOB price to the Government in the cost analysis. The nonrecurring costs include design and analysis along with static, fatigue, whirl, and flight testing. The cost of producing the UH-1D/H blade was estimated in the same manner as the candidate blades. For the 10,000th unit, this blade price was more than the stated value of $3000. The price of all blades was therefore adjusted so that the candidate blade prices are consistent with the given UH-1D/H blade price.

Blade Damage Analysis

Details of this analysis are described in the Reliability and Maintainability Sections, and the results as used in the cost analysis are presented in Table X. The values shown in the table are fractions of total life-cycle damage events as determined by the failure modes and effects analysis and damage disposition. The results of the UH-1D/H blade damage analysis show a user repair capability of 19% compared to the Government-specified user repairability for this blade of 12%. The reason for the increased user repairability is that the analysis assumes that organizational/intermediate level personnel will successfully attempt repairs that previously would have been dispositioned back to a higher repair level if such a facility existed.

Repair Costs

Repair of blade damage is resolved in the form of several repair kits applicable to all blades singly or in combination. For each expendable blade design, the maintainability analysis identifies the number and type of repair kit along

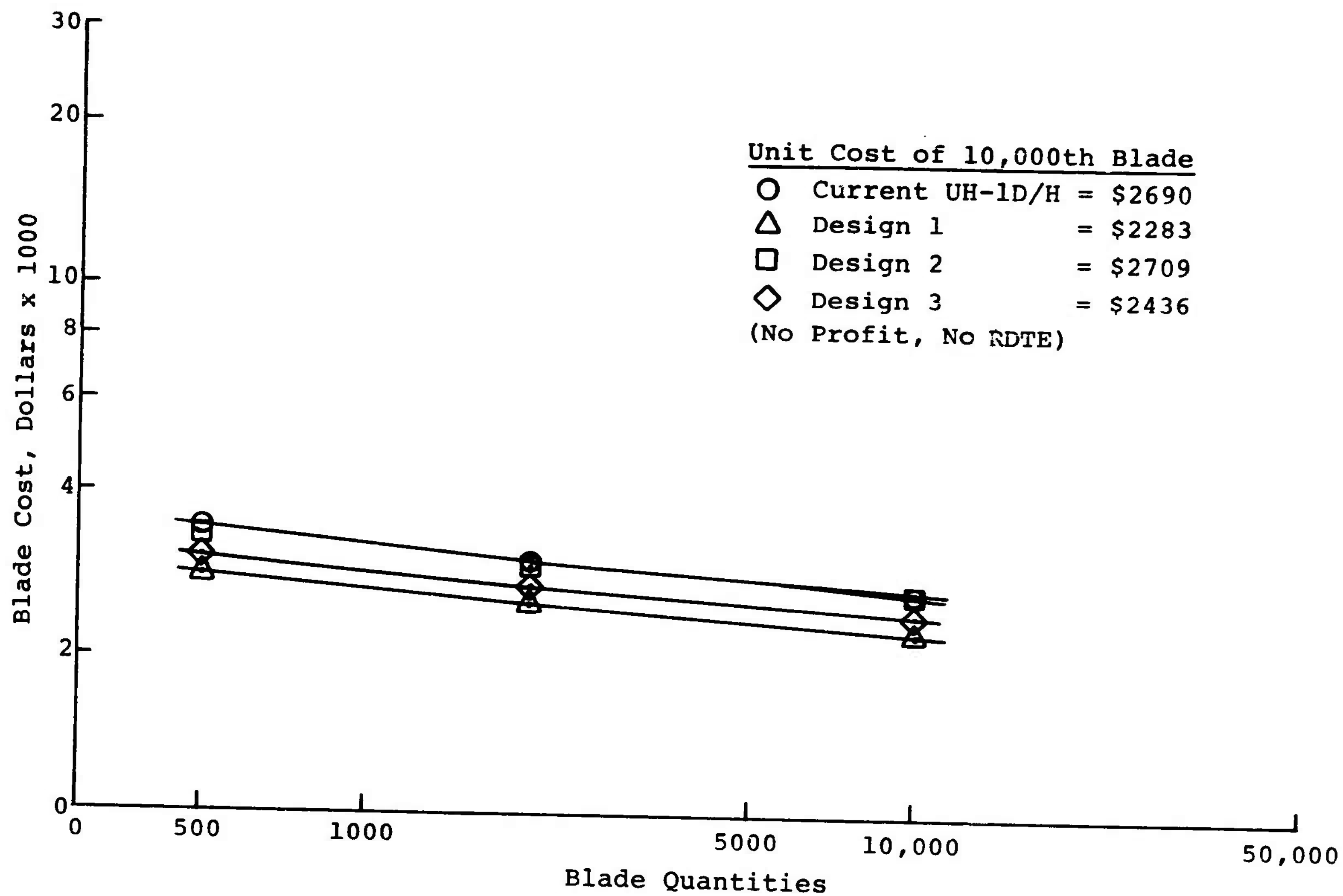

Figure 47. Blade Candidate Cost Estimates.

TABLE IX. COST OF NEW BLADES TO THE ARMY (DOLLARS, FOB)

	Prod. Cost Est.*	RDTE Cost per Unit	Profit	Blade Price to Army
UH-1D/H	2593	86	321	3000
Design 1	2186	113	275	2574
Design 2	2612	119	328	3059
Design 3	2335	124	296	2759

* Based on 10,000th unit of production and adjusted to agree with specified price of the current UH-1D/H blade.

TABLE X. RESULTS OF MAINTAINABILITY ANALYSIS

Symbols	Blade Damage Event Category	UH-1D/H	Design 1	Design 2	Design 3
	Fraction Repaired at Org. Level (on A/C)				
	Inherent Damage		.023	.003	.014
	External Damage	.033	.053	.090	.064
K_{BRO}		.033	.076	.093	.078
	Fraction Repaired at Inter. Level (off A/C)				
	Inherent Damage	.022	.022	.098	.056
	External Damage	.136	.140	.236	.332
K_{BRF}		.158	.162	.334	.388
K_{BR}	Total Fraction of Blades Repaired	.191	.238	.427	.466
	Fraction of Blades Scrapped at Org./Inter. Level				
	Inherent Damage	.223	.149	.086	.069
	External Damage	.586	.682	.487	.465
K_{BS}	Total Fraction of Blades Scrapped	.809	.831	.573	.534
	Total Blade Damage Disposition	1.000	1.000	1.000	1.000
BTBD	Blade Time Between Damage, blade hours	1063	1080	1283	913

with the mean-time-to-repair (MTTR). Table XI defines the kits, kit prices, and quantities necessary to perform the cost analysis on an aircraft life-cycle basis.

Support equipment required to repair blades using the designated repair kits is defined in the Maintainability Analysis. The price of equipment to support any or all of the kit repairs is estimated at $470, including transportation. Assuming that five sets of equipment will be required for a company of 25 aircraft, the cost per aircraft is approximately $94.00.

The material cost and the mean-time-to-repair the current UH-1D/H blade were determined in the same manner as the expendable blade design candidates for uniformity of the repair cost comparisons. The blade repair analysis described in the Maintainability section provides an estimated MTTR of 1.45 hours not including other associated hours such as inspection, removal and replacement, and requisition times which are accounted for separately from the actual repair time.

The allowable operating time (AOT) due to fatigue is assumed at 2500 hours for the UH-1D/H blade, and the same value is assumed for the expendable blade design candidates since the margins of safety are about the same.

Program Cost Analysis

The contractor-determined cost elements described above, along with cost elements supplied by the Government and presented in Appendix IV, can now be incorporated into the cost model to determine program life-cycle costs. The current UH-1D/H will be used as an example, while costs for all blade configurations are tabulated in Table XII.

Cost elements supplied by the Government and used in the various cost model equations are defined as follows:

N	=	Number of blades per aircraft	2
L	=	Aircraft life cycle, flt. hours	5000
C_c	=	Container cost, dollars	200
C_{SA}	=	Blade air shipping cost one way, dollars	130
C_m	=	Organizational level labor rate, dollars per hour	4.00
M_1	=	MMH in addition to MTTR at intermediate level, hours Basis: Inspection and disposition = 1.5 hours Removal and installation = 7.5 hours	9.0

TABLE XI. REPAIR KIT COSTS

Kit No. and Type	Kit Price (FOB)	Kit Quantities per A/C Life Cycle* Configuration: Current UH-1	Design 1	Design 2	Design 3
1. Blend Repair Kit	$ 9.89	1	2	2	3
2. Fiberglass Patch Kit	$32.37	0	0	7	10
3. Aluminum Patch Kit	$29.32	4	4	0	0
Average Repair Kit Price (FOB) per repair		$24.40 **	$22.80	$27.70	$27.20
T_R = Mean-Time-To-Repair, hrs. (Org. and Inter. combined)		1.45	1.39	1.99	2.16

* Support equipment required to repair blades using the designated repair kits is defined in the Maintainability Analysis. The price of equipment to support any or all of the kit repairs is estimated at $470 including transportation. If 5 sets of equipment are required for a company of 25 aircraft, the cost per aircraft is approximately $94.00.

** For the current UH-1H blade with depot repair, the average repair kit price is $5.00 (see Appendix IV). More sophisticated repair kits are required for expendable/field repairable operation.

TABLE XII. SUMMARY OF BLADE COSTS PER AIRCRAFT LIFE CYCLE

	Current UH-1D/H				
	Repairable	Expendable	Design 1	Design 2	Design 3
1. Initial Costs - Dollars					
Outfitting Production A/C	6000	6000	5148	6118	5518
Spare Blades and Containers	1103	1006	825	585	774
Spare Parts	5	6	7	9	11
2. Operating Costs - Dollars					
Org./Inter. Blade Repair Labor	30	52	57	87	154
Org./Inter. Blade Repair Parts	99	132	138	169	219
Org./Inter. Blade Scrap/Fatigue	7431	19313	15733	11226	14793
Depot Level Blade Repair	1894				
Depot Level Blade Scrap	9882				
3. Attrition Costs - Dollars					
Blade Replacements	9390	9390	8112	9567	8667
Total Blade Cost per Aircraft Life Cycle - Dollars	35834	35899	30020	27761	30136

M_2 = MMH in addition to MTTR at Org. level, hours 1.5
Basis: Inspection and disposition = 1.5 hours

M_3 = MMH to scrap blade at Org./Inter. level, hours 15.0
Basis: Removal and installation = 7.5 hours
Requisition of replacement = 3.0 hours
Obtaining replacement = 3.0 hours
Inspection and disposition = 1.5 hours

C_{sp} = Shipping cost of repair materials, fraction of cost 1.10

C_{SC} = Container shipping cost one way, dollars 45.0

K_A = Number of blades lost to attrition 3.0

<u>Blade Damage Events per Aircraft Life Cycle</u>:

$$N_{bf} = \left(\frac{N.L}{BTBD} - N\right)$$

$$= \left(\frac{2 \times 5000}{1063} - 2\right)$$

$$= 7.41$$

<u>Fraction of Blade Damage Fatigue Retired:</u>

$$K_{BF} = (K_{BR})^{1.395} / (AOT \times 10^{-2})^{1.835}$$

$$= 27\ (.184)^{1.395} / (25)^{1.835}$$

$$= .0073$$

Initial Costs:

Blade outfitting = n C_{nb}= 2 (3000) = \$ 6,000

Spare blades and containers

$= \left[N_{bf}/20\right] \left[(K_{BS}+K_{BF}) (C_{nb}+C_c+C_{SA})\right]$

$= \left[7.41/20\right] \left[(.809+.007) (3000+200+130)\right]$

$= .371 (.816) (3330)$ = 1,006

Spare materials

$= \left[N_{bf}/20\right] \left[K_{BR}(C_pC_{sp})\right] +C_E/20$

$= .371 \left[.191 (24.40) (1.10)\right] + 94/20$

$= 1.9 + 4.7$ = 6

Operating Costs:

Organizational/Intermediate repair labor

$= N_{bf} \left[C_m(M_1+T_R) K_{BRF}+C_m(M_2+T_R) K_{BRO}\right]$

$= 7.41 \left[4 (9+1.45) .158 + 4 (1.5+1.45) .033\right]$

$= 7.41 \left[6.4 + .366\right]$ = 52

Organizational/Intermediate repair materials

$= N_{bf} \left[(C_pC_{sp}) (K_{br})\right] +C_E$

$= 7.41 \left[(24.40) (1.10) (.191)\right] + 94$

$= 7.41 (5.2) + 94$ = 132

Organizational/Intermediate scrap and fatigue retire

$= N_{bf} \left[(K_{BS}+K_{BF}) (C_{nb}+C_{SA}=C_{SC}+C_mM_3)\right]$

$= 7.41 (.809 + .00741) \left[3000+130+45+4(15)\right]$

$= 7.41 (.816) (3235)$ = 19,313

Attrition Costs:

Attrition costs = $K_A (C_{nb}+C_{SA})$ = 3.0 (3000+130) = 9,390

Total Program Cost/Aircraft Life Cycle = \$35,899

Discussion of Cost Analysis

A review of the cost model inputs and results indicates that the following items most significantly affect the expendable blade program costs per aircraft life cycle:

(1) New blade costs
(2) Blade damage resistance
(3) Blade repairability

The cost model equations were adapted to a Hewlett Packard 2000C time-sharing computer so that variations in program costs due to the above factors could be easily evaluated. Figure 48 shows program costs as a function of varying blade prices,with other cost factors remaining the same as determined in the design analysis. It can be readily seen that for a given blade price, Design 2 is the most effective in terms of its combined ability to resist damage and to be repaired once damage has occurred. Also shown on the plot are symbols denoting the comparable blade prices as determined by the contractor in this study.

A variation in the capability of the blade designs to resist damage is shown in Figure 49 in terms of program costs versus blade-time-between-damage. This plot indicates that Design 3 is favorable in terms of blade price and repairability for a given BTBD. However, the study results indicate that this design has less resistance to damage and a lower BTBD than Designs 1 and 2; consequently, it is not the preferred design from a program cost standpoint.

The third significant cost factor is the capability of the blade design to be repaired once damage has occurred. The actual repair costs are of little significance, but the scrap costs, if the damage cannot be repaired, are very important. Figure 50 describes program costs versus the fraction of blade damage repaired at the user level. As shown in the plot, blade Designs 1 and 2 are competitive in terms of program costs for a given repairability in the range determined by this study. However, Design 1 is less repairable according to this study, as shown by the symbols on the plot, while Design 2 again is the more favorable concept.

In summary, each of the expendable blade designs offers some advantage over the current UH-1D/H blade from a life-cycle blade program cost standpoint:

- Blade Design 1 is the least expensive to produce but lacks the degree of field repairability incorporated in the other two designs.

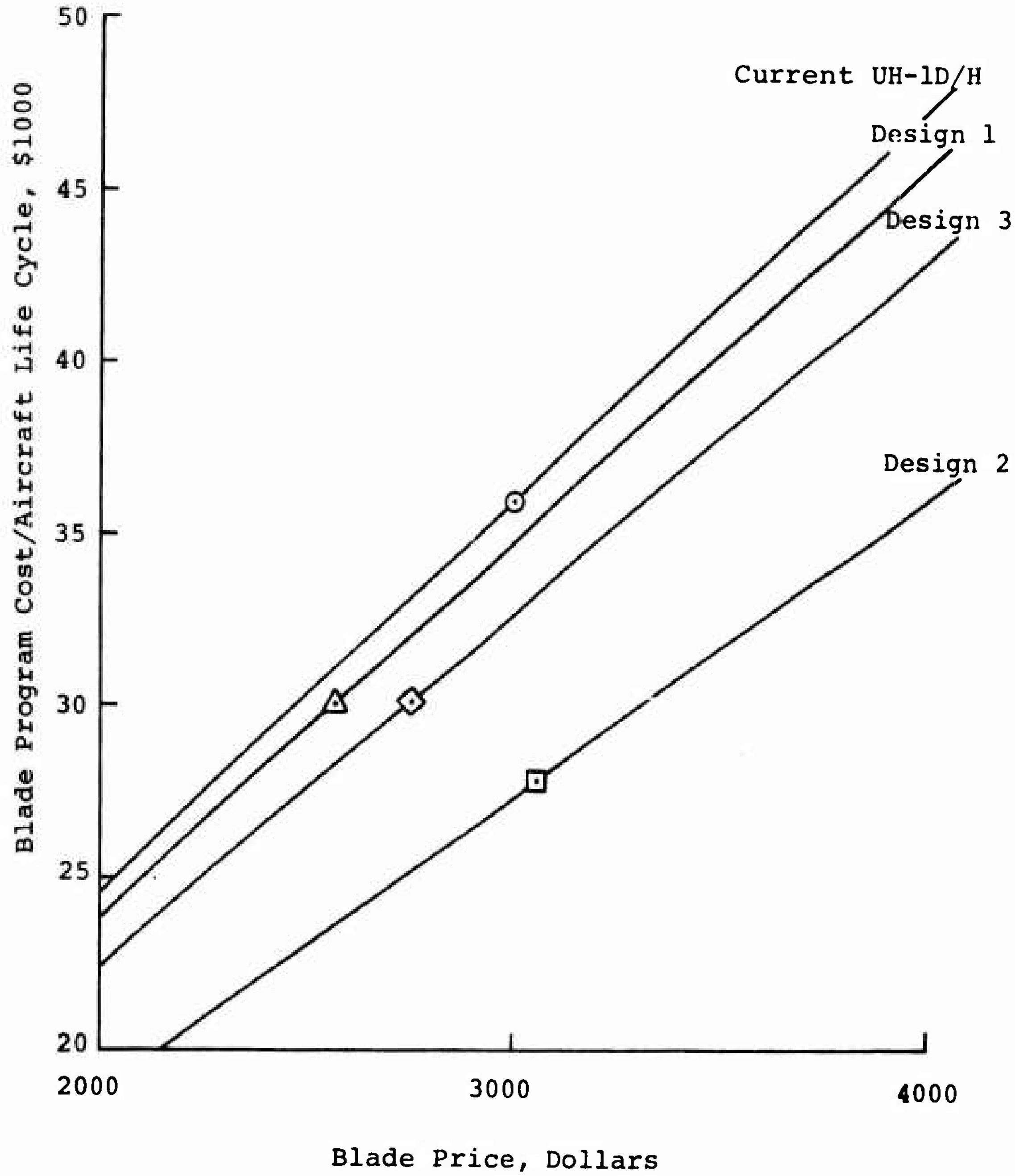

Figure 48. Program Cost vs New Blade Cost.

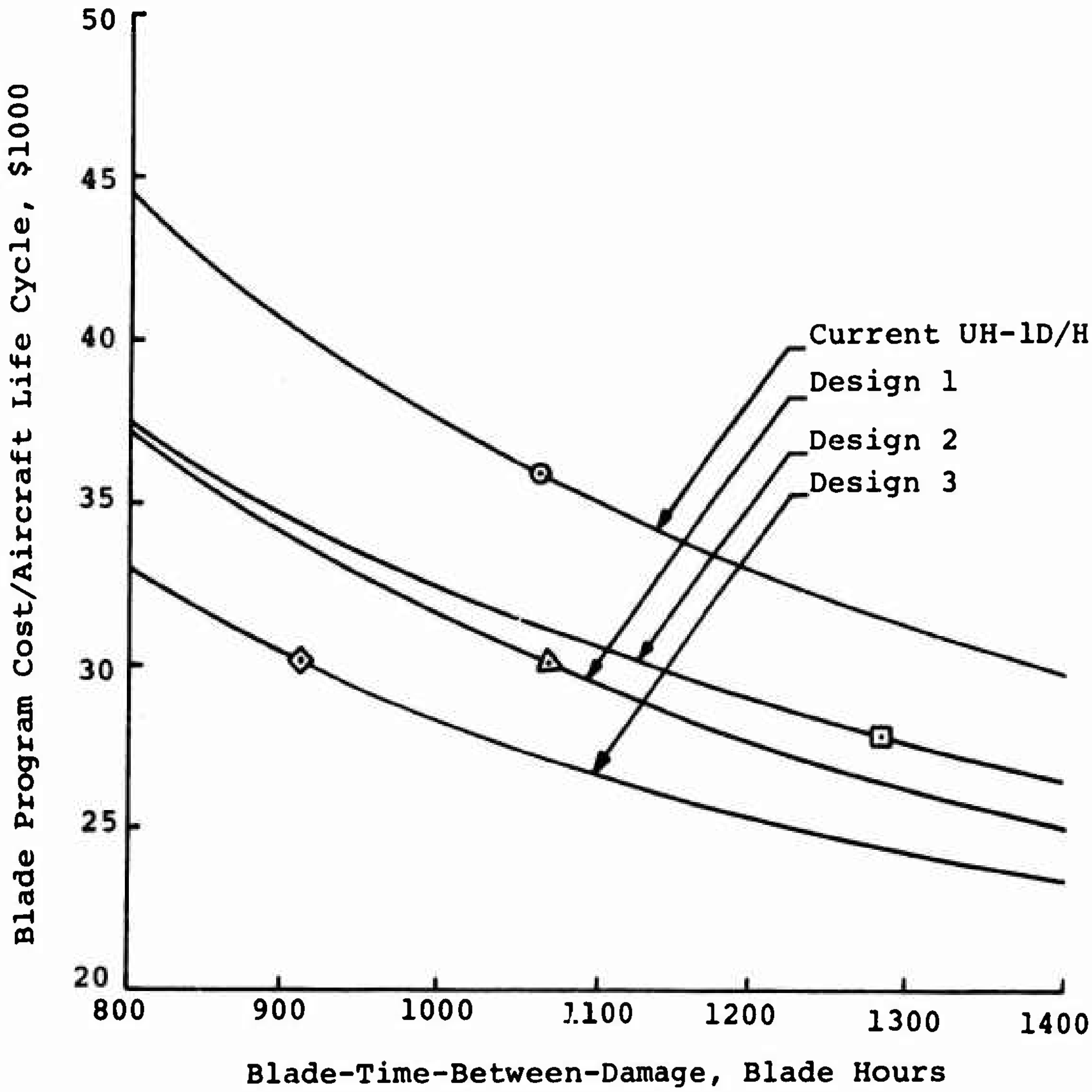

Figure 49. Program Cost vs Blade-Time-Between-Damage.

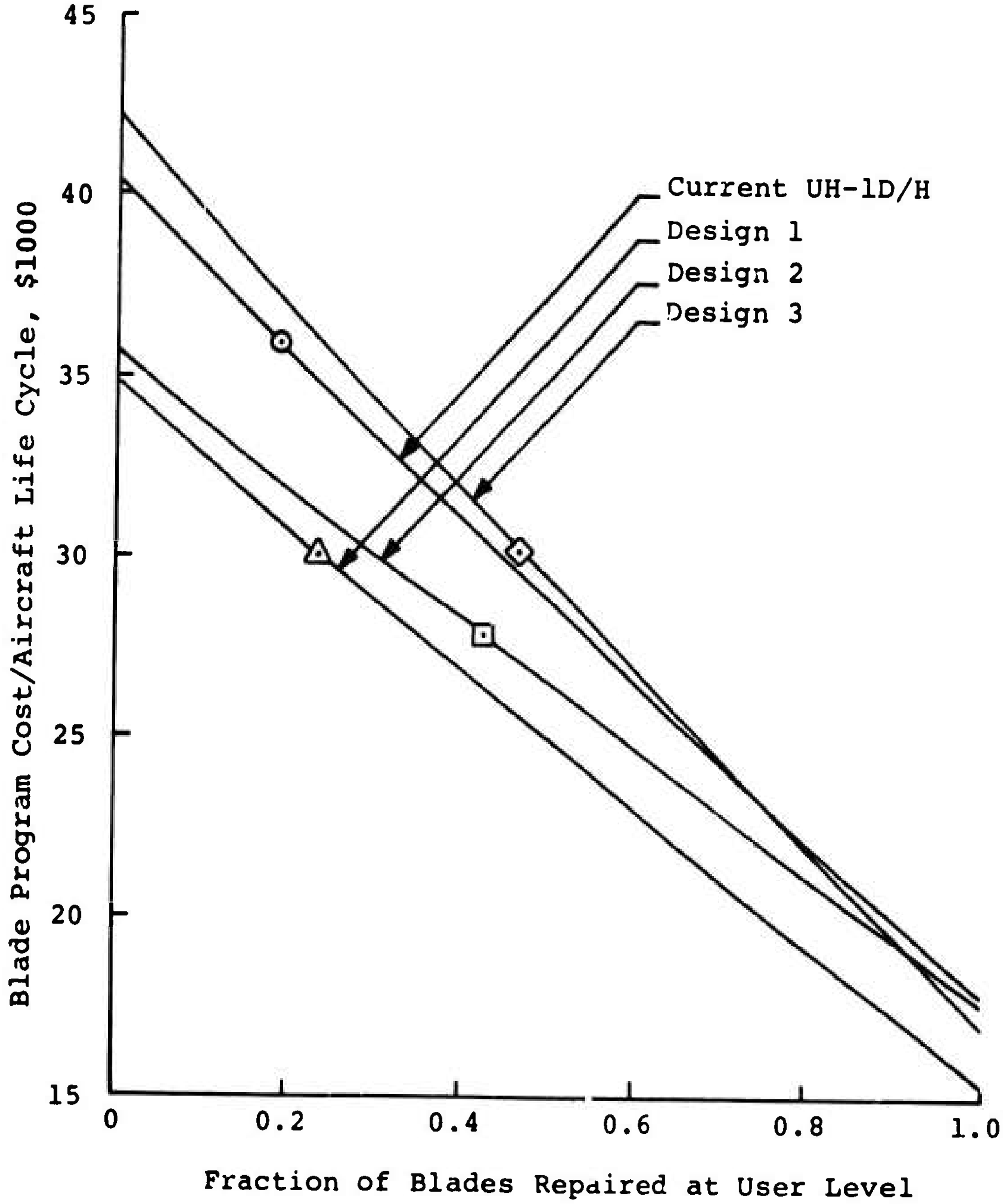

Figure 50. Program Cost vs Blade Repairability.

- Blade Design 3 is a moderately priced blade but has less ability to withstand damage.

- Blade Design 2, while costing more to produce, is the preferred design because its ability to resist damage and to be repaired in the field outweighs any price disadvantage compared to the other designs.

The results of this life-cycle cost analysis indicate that the preferred expendable blade Design 2 will reduce blade program cost by 23% compared to the current UH-1D/H concept. Table XIII compares 10-year life-cycle costs of all blade designs with the UH-1D/H for fleet sizes of 500, 1000, and 2000 aircraft. Design 2 shows an annual blade program cost reduction of 1.6 million dollars over the current UH-1D/H blade concept for a fleet size of 2000 aircraft.

Sensitivity of Cost Factors

A variation in the critical cost factors that make up life-cycle costs provides an assessment of the risks involved should the expendable blade concept be incorporated. Sensitivities of the significant cost factors discussed earlier are shown below for Blade Design 2:

Cost Factor Variation	Program Cost Variation
±10% Blade Price	±9%
±10% Blade Damage Rate	±8%
±10% Blade Repair/Scrap Fraction	±5%

Blade price is the most significant cost factor to be considered, followed closely by the ability of the blade to withstand damage. The ability to repair the blade at the organizational or intermediate level is the least important of the significant cost factors.

One aspect of operating costs that is not considered in this study is the human nature element. It is a generally established fact that when a blade is damaged, a new replacement will be used if available. The damaged blade, even though repairable, is then subject to further damage by hangar rash, handling, etc. For the extreme situation, the fraction of blades repaired would go to zero, but as shown in Figure 50, Designs 1 and 2 still yield a program cost reduction of about 12%.

TABLE XIII. COMPARISON OF LIFE-CYCLE BLADE PROGRAM COST VERSUS FLEET SIZE

	Fleet Size			Percent of UH-1D/H
	500 A/C	1000 A/C	2000 A/C	
Current UH-1D/H	17.95	35.90	71.80	100.0
Design 1	15.01	30.02	60.04	83.6
Design 2	13.88	27.76	55.52	77.3
Design 3	15.07	30.14	60.27	83.9

Note: Costs are shown in millions of dollars.

CONCLUSIONS

The study performed in this program shows that application of current state of the art to design and manufacturing techniques, and to material selection, can substantially reduce the life-cycle costs of helicopter main rotor blades in U.S. Army service. Of the four design concepts on which studies were initiated, three proved, within the limitations of a theoretical investigation, to have significant cost advantages over the current UH-1H main rotor blade, without serious impairment of aerodynamic, dynamic, or structural characteristics.

Each of the three successful concepts achieves a reduction in life-cycle costs by means of an advantage in a specific cost area. These specific advantages and the design features contributing to them are listed below, for each design.

Design 1

A moderate life-cycle cost advantage is achieved by reducing manufacturing and material costs and, therefore, initial procurement cost. This concept has the lowest price of the three, by virtue of its simple design and minimum number of component parts. Vulnerability and repairability differ very little from those of the current UH-1H blade, so that the reduction in life-cycle costs directly reflects the reduction in initial procurement cost.

Design 2

Although marginally more expensive in initial procurement cost than the current UH-1H blade, this concept exhibits lower life-cycle costs than either the current blade or Designs 1 or 3, by a substantial margin. The materials combination of stainless steel and glass-fiber-reinforced plastic affords a very great improvement in environmental protection and in vulnerability to external damage. This major reduction in vulnerability, combined with an increase in repairability, results in life-cycle costs some 23% below those of the current blade.

Design 3

The initial procurement cost of this concept falls between those of the current blade and Design 1. Incorporation of a unique design feature, a buried shear web on the chord plane, affords a great improvement in repairability, which more than offsets an increase in vulnerability to external damage.

The combination of reduced procurement cost and improved maintainability results in life-cycle costs little more than those of Design 1.

It is concluded, therefore, that a blade design incorporating a formed sheet stainless steel spar and a glass-fiber-reinforced plastic after body is superior to all other concepts within the constraints imposed by the section properties of the current UH-1H main rotor blade. Freed of these constraints, further advantage could be shown by reducing manufacturing cost by at least three means. First, the separate nose ballast could be eliminated by increasing the thickness of the nose skin; second, spar sheet-metal thicknesses could be chosen such that the fiberglass aft skins could be constant thickness, requiring no build-up with additional laminations; and third, the partial span stiffener could be replaced by a full-length structural member. Since these design changes would prevent matching the current UH-1H blade section properties, this approach would be appropriate for a new aircraft program, where the airframe and rotor design is still fluid, and more sophisticated and complete dynamic analyses can be performed.

The formed sheet-metal spar, as distinct from an extrusion, can be varied in section along the span, providing a significant advantage in optimizing airfoil sections for future higher performance helicopters. Intangible advantages, such as a reduction in the number of blades in the logistics pipeline and a reduction in the maintenance manpower required, accrue directly from the decrease in vulnerability.

A general conclusion can be drawn with respect to the elimination of depot repair. Table XII shows that the life-cycle cost difference between repairable and expendable operation of the current UH-1H blade is less than 0.2%, and therefore negligible. The decision to incorporate depot repair in a new or existing blade program would be determined by such factors as logistics and availability of manpower. For an existing blade the availability of depot facilities and for a new program the first cost of such facilities will be overriding considerations not explored in this study. The study is limited to one particular aircraft system and the conclusions cannot be generalized for larger, more complex, and more expensive rotor systems; but for helicopters in the UH-1H class, the expendable concept is shown to be valid.

RECOMMENDATIONS

It is recommended that a program be initiated to perform the detail design, analysis, and manufacture of a prototype test quantity of expendable helicopter main rotor blades. Three of the configurations studied in the course of this program show promise of providing significant cost savings to the Army, either through lower initial cost or through increased utilization, and all are worthy of consideration for development and evaluation.

Ground structural tests, whirl tests, and flight tests should be performed. These blades can be designed to match the section properties of the current UH-1D/H main rotor blade.

It is further recommended, however, that advantage be taken of the unique ability of the method of construction of Design 2 for the airfoil section to vary along the span, and by utilizing sophisticated dynamic analysis techniques, available through current advances in the state of the art, to optimize the blade around the UH-1H airframe and mission parameters. The constraints of the current blade design do not allow full advantage to be taken of this structural concept.

The resulting blade could be flight tested on the UH-1H and would show performance benefits in addition to the cost benefits that have been defined.

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APPENDIX I

FAILURE MODES AND EFFECTS ANALYSIS

Tables XIV through XVII provide detailed breakdowns of the modes of failure and their frequencies of occurrence for the current UH-1D/H blade and Designs 1, 2, and 3 of the expendable blade concepts. Also included in these tables are columns indicating the effects and consequences of the described failures, the methods of detection, compensating provisions, and ultimate dispositions. In the last column, indicating the dispositions, the current blade is treated as both a repairable (as it is currently operated) and as an expendable blade. The dispositions are shown parenthetically for the "expendable" version. For the expendable blade concepts, the choices of disposition are (1) repair at organizational level, (2) repair at intermediate (local depot) level, or (3) scrap. The repairable version of the current blade has two more options: (4) return to depot (continental U.S.) and repair, or (5) return to depot and scrap.

The damage incidents used in the FMEA correspond to those given in Table H-I, page 112, of Reference 2.

TABLE XIV. FAILURE MODES AND EFFECTS ANALYSIS, CURRENT UH-1D/H BLADE

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	INHERENT (PART) CAUSES OF FAILURE					
3.0	Excessive vibration (Vibra. beyond spec., mismatched, out of adjustment, unable to adjust, unbalanced, and unstable)	Water leak due to skin-to-beam-doubler bond failure.	Delay of takeoff, or might cause return to base. Remove.	Noise, track path, crew discomfort, poor handling, visual.		SCRAP (SCRAP)
3.0	Excessive vibration.	Water leak due to skin-to-spline bond failure.	Delay of takeoff, or might cause return to base. Remove.	Noise, etc., visual.		SCRAP (SCRAP)
0.4	Excessive vibration.	Leak path at root end.	Delay of takeoff, or might cause return to base. Remove.	Noise, etc., visual.		SCRAP (SCRAP)
	NON-EDGE VOIDS BETWEEN SURFACES AS FOLLOWS:					
4.7	Excessive vibration.	Abrasive strip and noseblock 1" wide or more.	Delay of takeoff, or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
		OUTBOARD OF STATION 100				
10.0	Excessive vibration.	Skin and core >25 in^2	Might cause return to base; scrap.	Noise, etc., visual.		SCRAP (SCRAP)
40.0	Excessive vibration.	Skin and core <25 in^2 but>1" wide	Complete mission, remove.	Noise, etc., visual.		SCRAP (SCRAP)
13.6	Excessive vibration.	Abrasive strip and beam doubler >10 in^2 single or ≥ 30 in^2 total.	Delay in takeoff, or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
2.5	Excessive vibration.	Noseblock and beam > 5" by 2" or > 18 in^2 total.	Delay in takeoff , or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
2.5	Excessive vibration.	Beam doubler and beam > 1" by 3" or > 15 in^2 total.	Delay in takeoff , or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
		INBOARD OF STATION 100				
0.5	Excessive vibration.	Abrasive strip and beam > 2 in^2 single or > 10 in^2 total.	Delay in takeoff , or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
0.5	Excessive vibration.	Beam doubler and beam > .5" by 1.0" or > 3 in^2 total.	Delay in takeoff , or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
0.5	Excessive vibration.	Noseblock and beam > .5" by 1.0" or > 3in^2 total.	Delay in takeoff , or might cause return to base. Remove.	Noise, etc., visual.		DEPOT (SCRAP)
2.0	Excessive vibration.	Skin and core.	See Note 4.	Visual, vibration.	Preflight insp. reduces prob. of crash.	DEPOT (SCRAP)
0.3	Excessive vibration.	Spline fatigue. (Crack or kink).	See Note 3.	Vibration.		SCRAP (SCRAP)
3.0	Excessive vibration.	Delamination of skin at T.E.	Might cause return to base.	Vibration, visual.		DEPOT (SCRAP)
3.0	Excessive vibration.	Turbulence due to spline corrosion.	Might cause return to base.	Vibration, visual.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
2.8	Excessive vibration.	Delamination of ext doublers.	See Note 4.	Vibration, visual.	Visual insp. and repair reduces probability of crash.	SCRAP (SCRAP)
5.8	Excessive vibration.	Retention bushings worn, cracked, or degraded by galvanic action.	Might cause return to base.	Visual.		DEPOT (SCRAP)
0.6	Excessive vibration.	Ext doublers cracked or yielded.	See Note 4.	Visual, vibration.	Visual insp. reduces probability of crash.	SCRAP (SCRAP)
0.3	Excessive vibration.	Box beam fatigue fail.	Unbalance may cause extensive aircraft damage and personnel injury.	Vibration.		SCRAP (SCRAP)
0.5	Excessive vibration.	Box beam doubler fatigue fail at alum-steel joint or elsewhere.	Cracks all the way through doubler and more than 3" long may propagate and cause a forced landing.	Vibration.		DEPOT (SCRAP)
6.0	Excessive vibration.	Skin fatigue crack.	See Note 2.	Vibration, visual.		DEPOT (SCRAP)
2.0	Excessive vibration.	Voids within spec., but stiffness reduced by bond fatigue.	Degradation in performance. Return to base.	Vibration, visual.		DEPOT (SCRAP)
1.0	Excessive vibration.	Noseblock fatigue fail at aluminum-brass joint.	Distorts contour slightly. No flight effect, but would cause abrasion strip delamination.	Visual.	Not a principal load carrying member.	DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
10.0	Embrittlement.	Skin dented by F.O.'s or abnormal handling.	No mission effect. Scrap blade to prevent fatigue cracks in flight.	Visual.		SCRAP (SCRAP)
3.6	Embrittlement.	Spline chips in abnormal handling.	Slight degradation in performance. Scrap blade to prevent fatigue cracks in flight.	Visual, vibration.		SCRAP (SCRAP)
150.0	Deterioration.	Crack in skin.	Slight degradation in performance. Remove.	Visual, vibration.	Cracks reported as "Deterioration" would involve low stress area.	INTER=60 DEPOT=90 (INTER=60 SCRAP=90)
20.0	Deterioration.	Spline eroded, cracked, corroded.	Slight degradation in performance due to air turbulence. Crack, see Note 3.	Visual, vibration.		SCRAP (SCRAP)
13.0	Deterioration.	External doublers corroded or not smooth after repair.	Corrosion would reduce fatigue life.	Visual, vibration.		SCRAP (SCRAP)
10.3	Deterioration.	Abrasive strip abraded or not smooth after repair.	Slight increase in air turbulence.	Visual, vibration.		DEPOT (SCRAP)
5.0	Bonding delaminated, loose, or poor condition.	Bond failure between abrasion strip and beam doubler ≥ 10 in.^{2} single or ≥ 30 in.^{2} total.	Degradation in performance might cause return to base. Remove.	Vibration, visual		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
30.0	Bonding delaminated, loose or poor condition.	Skin and core > 25 in^2.	Might cause return to base. Scrap.	Vibration, visual.		SCRAP (SCRAP)
119.0	Bonding delaminated, loose or poor condition.	Skin and core < 25 in^2 but $> 1"$ wide.	Complete mission. Remove.	Vibration, visual.		SCRAP (SCRAP)
20.0	Bonding delaminated, loose or poor condition.	Skin and spline.	Might cause return to base.	Vibration, visual.		DEPOT (SCRAP)
19.0	Bonding delaminated, locse or poor condition.	Skin and Beam doubler.	See Note 2.	Vibration, visual.		DEPOT (SCRAP)
0.3	Bonding delaminated, loose or poor condition.	Ext doubler or ext doubler and skin.	See Note 4.	Vibration, visual.	Visual insp. prevents large delaminations causing crashes.	SCRAP (SCRAP)
0.3	Bonding delaminated, loose or poor condition.	Grip or drag plate edge void deeper than .5" at tip.	See Note 4. Scrap.	Vibration, visual.	Visual insp. prevents large delaminations causing crashes.	SCRAP (SCRAP)
1.2	Bonding delaminated, loose or poor condition.	Grip plate, less than above.	Slight increase in air turbulence.	Visual.		DEPOT (SCRAP)
1.2	Bonding delaminated, loose or poor condition.	Drag plate, less than above.	No performance effect.	Visual.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
10.0	Bonding delaminated, loose or poor condition.	Spar and core.	Sufficient unbonding will reduce fatigue life of skin. Scrap.	Visual, spanwise crack in skin at spar edge.		SCRAP (SCRAP)
32.4	Excessive wear.	Pitted spline.	Slight degradation in performance due to air turbulence. Reduced fatigue life.	Visual.		DEPOT (SCRAP)
5.4	Excessive wear.	Skin.	Slight degradation in performance due to air turbulence. Reduced fatigue life.	Visual.		DEPOT (SCRAP)
0.6	Excessive wear.	Ext doublers or grip plates.	Reduced fatigue life. Safety hazard.	Visual.		DEPOT (SCRAP)
65.0	Excessive wear.	Worn retention bushings.	Delay of takeoff or return to base.	Vibration.		DEPOT (SCRAP)
5.0	Excessive wear.	Abrasion strip, 18.8 CRES, eroded or abraded.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
4.0	Excessive wear.	T.E. abraded or eroded.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
1.2	Excessive wear.	Skin near abrasion strip eroded, uneven, or abraded.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
1.2	Corroded.	Abrasion strip eroded.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
2.5	Corroded.	Skin at T.E.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
4.7	Corroded.	Spline.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
2.2	Corroded.	Skin at abrasion strip.	Slight degradation in performance due to air turbulence.	Visual.		DEPOT (SCRAP)
0.1	Corroded.	Ext doublers, grip or drag plates.	Reduced fatigue life, safety hazard.	Visual.		SCRAP (SCRAP)
13.9	Leaking.	Due to skin to beam doubler bond failure.	Delay of takeoff or forced return to base.	Vibration, visual.	Leak into beam I.D. will spin out drain hole in tip.	SCRAP (SCRAP)
11.0	Leaking.	Skin to spline bond failure.	Delay of takeoff or forced return to base.	Vibration, visual.	Leak into beam I.D. will spin out drain hole in tip.	SCRAP (SCRAP)
EXTERNAL CAUSES OF FAILURE						
24.0	Battle damage. Holes all the way through.	Beam and beam doublers.	30-caliber bullet hits would cause forced landing. Larger projectiles or jagged holes inboard of station 105 would cause the effects of Note 1.	Vibration.		SCRAP (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
39.0	Battle damage.	Skin and core > 2" dia or > 1" by 4".	See Note 2. Leakage during rainstorm would decrease stability. Scrap.	Noise, visual.		SCRAP (SCRAP)
185.0	Battle damage.	Skin and core < 2" dia and < 1" by 4".	A nonsmooth hole in a high stress location might cause the effects of Note 2. Otherwise, only slight increase in turbulence.	Noise, visual.		SCRAP (SCRAP)
8.0	Battle damage.	Spline.	Might propagate and cause the effects of Note 3.	Vibration, visual.		SCRAP (SCRAP)
1.0	Battle damage.	Ext doublers or grip plates.	See Note 4.	Vibration, visual.		SCRAP (SCRAP)
0.4	Dented.	Beam.	No mission effect. Fatigue life would be limited. Scrap.	Visual.	Damage propagation is slow inboard of Station 105 where doubler is steel.	SCRAP (SCRAP)
4.0	Dented.	Beam doubler.	No mission effect. Decrease in life.	Visual.	Damage propagation is slow inboard of Station 105 where doubler is steel.	DEPOT (SCRAP)
346.0	Dented.	Skin or skin and core.	Would cause air turbulence in relation to size and location. Might cause return to bas-	Visual, vibration.	See Note 5.	INTER=134.4 DEPOT=201.6 (INTER=134.4 SCRAP=201.6)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
5.6	Dented.	Spline > .040" deep.	Fatigue life too limited for safe use.	Visual.		SCRAP (SCRAP)
10.0	Dented.	Spline < .040" deep.	Hammer out on aircraft if > .020" deep.	Visual.		ORG. (ORG.)
4.0	Dented.	Ext doubler grip or drag plate > .012" deep.	See Note 1.	Visual.	[illegible] repair needed [illegible] < .012" deep	SCRAP (SCRAP)
40.0	Dented.	Abrasive strip 18.8 CRES.	Slight increase in turbulence. Polish out if affects performance.	Visual, vibration.	Not a load carrying part.	ORG. (ORG)
3.0	Foreign object damage.	Nick in spline > .120" deep.	No mission effect. Remove blade. Remaining fatigue life too limited for safe use.	Visual, vibration.		SCRAP (SCRAP)
12.0	Foreign object damage.	Nick in spline < .120" deep but > .008" deep	Slightly increases air turbulence but repair should not require removal.	Visual.	No maintenance action required < .008" deep.	ORG. (ORG.)
30.0	Foreign object damage.	Skin and core crushed.	Would cause air turbulence in relation to size and location. In worst case, might cause loss of control.	Vibration, visual.	Core is not a principal load carrying member.	DEPOT (SCRAP)
57.0	Foreign object damage.	Nick or scratch in abrasive strip > .012" deep.	Slight increase in air turbulence. May propagate but at slow rate. Remove.	Visual, vibration.	Not a safety of flight part.	DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
6.0	Foreign object damage.	Nick or scratch in abrasive strip < .012" deep.	No performance effect. Repair on aircraft.	Visual.		ORG. (ORG.)
0.03	Foreign object damage.	Box beam split in two.	Unbalance may cause extensive aircraft damage and personnel injury.	Loss of control.		SCRAP (SCRAP)
0.09	Foreign object damage.	Box beam gashed or cracked > 3" long and all the way through wall inward of Station 105 (or 2" outward).	See Note 1.	Degradation of control.		SCRAP (SCRAP)
0.27	Foreign object damage.	Box beam damaged less than above.	Forced landing or return to base. Scrap.	Vibration.		SCRAP (SCRAP)
0.12	Foreign object damage.	Box beam doubler gashed or cracked all the way through doubler and > 3" long.	May propagate and cause a forced landing. Scrap.	Vibration, visual during next preflight if a gash.		SCRAP (SCRAP)
1.35	Foreign object damage.	Beam doubler damaged less than above.	May cause return to base. Remove. Not repairable at int. level even if only scratched.	Vibration, visual during next preflight if a gash.		DEPOT (SCRAP)
140.68	Foreign object damage.	Nick or scratch in skin > .008" deep.	See Note 2. Remove blade if polishing out will leave less than .008".	Visual.		INTER= 56.27 DEPOT= 84.41 (INTER= 56.27 SCRAP= 84.41)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
0.06	Foreign object damage.	Ext doublers, grip or drag plates ruptured.	See Note 4. Scrap.	Vibration, visual.		SCRAP (SCRAP)
0.6	Foreign object damage.	Ext doublers, grip or drag plates gashed or nicked > .012" deep or cracked.	See Note 4. Scrap.	Vibration, visual.		SCRAP (SCRAP)
1.8	Foreign object damage.	Ext doublers, grip or drag plates nicked or scratched < .012" deep.	May be repaired on aircraft.	Visual.		ORG. (ORG.)
20.0	Punctured thru one surface.	Beam and beam doubler.	.30-caliber bullet hits would cause forced landing. Larger projectiles inboard of Station 105 might propagate and cause crash.	Vibration.		SCRAP (SCRAP)
40.0	Punctured thru one surface.	Abrasive strip.	Slight increase in air turbulence.	Visual.		DEPOT (SCRAP)
240.0	Punctured.	Skin and core.	Nonsmooth hole in a high stress location might cause the effects of Note 2.	Visual, vibration.	Smooth hole should have no mission effect.	DEPOT (INTER = 96 SCRAP = 144)
2.0	Punctured.	Ext doublers, grip or drag plates.	See Note 4. Scrap.	Visual, vibration.		SCRAP (SCRAP)
129.0	Torn skin and in some cases, core also.	Tree strike, handling, tools, F.O.D.	See Note 2.	Visual, vibration.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
126.4	Overspeed.	Emergency operation, governor failure, pilot error.	May cause rupture or crack in retention parts or beam. If no flight effects, the need to re-move, inspect, and possibly scrap depend on extent of overspeed.	Indicator in cockpit if pilot notices.	Specified RPM's for specified short durations require no repair if occur in normal flight attitude under normal g forces.	DEPOT (SCRAP)
9.3	Crash damage.	One of blades hits ground, water, or dense foreign object.	Fatigue life of any undamaged portions assumed too limited for safe use. Scrap both blades.	Visual.		SCRAP (SCRAP)
1.6	Crash with only slight or no blade impact.	Inspection of aircraft concludes that blade has been overstressed or over-heated past safe use or twisted.	Scrap blade or blades.	Visual.		SCRAP (SCRAP)
0.4	Crash with only slight or no blade impact.	Overstress not obvious in on-aircraft inspection.	Retention bolts must be removed; bushing area and root end inspected for indication of overstress. If not overstressed, repair as needed.	Visual.		DEPOT (SCRAP)

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
22.6	Overstress.	Aircraft over-loaded, out-of-envelope maneuvers.	May cause rupture, crack or yield of T.E. or retention parts. If no flight effects, fatigue life may be too limited for safe use. Pilot's log must be compared with inspection instructions. If instruction is not to scrap, retention bolts should be removed and inspected. If bolt or material around bushing has yielded, scrap blade.	Pilots log.	Specified over torques for specified short durations require no repair until a specified accumulation.	SCRAP (SCRAP)
92.7	Sudden stop.	Blade on or near ground hits an unmovable object.	Scrap both blades.			SCRAP (SCRAP)
2263.6	TOTAL					

TABLE XIV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION

NOTE 1: Damage would propagate to cause separation of beam with resulting rotor unbalance and loss of lift. Secondary effects would be excessive coning, flapping, or out-of-track. Probability of crash decreased from 1.0 at root to slightly less near tip.

NOTE 2: Skin damage might propagate and cause return to base if in outboard two-thirds of span, or forced landing if in inboard one-third.

NOTE 3: Spline rupture in first one-third of span would propagate across chord and cause beam to split. Rupture near tip would allow return to base. Cracks through intermediate span locations would cause forced landings.

NOTE 4: Damage may propagate and cause other blade parts to be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.

NOTE 5: In the outboard 4 feet of span, dents in skin (not through) that do not produce a void detectable by tapping with a coin and do not cause vibration require no repair. Inboard of this, only dents $<$.060" deep require no maintenance action.

TABLE XV. FAILURE MODES AND EFFECTS ANALYSIS, DESIGN 1

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	INHERENT (PART) CAUSES OF FAILURE					
	NON-EDGE VOIDS BETWEEN SURFACES AS FOLLOWS:					
2.0	Excessive vibration (Vibra beyond spec., mismatched, out of adjustment, unable to adjust, unbalanced, and unstable.)	Abrasion sheath and spar >1" wide.	Delay of takeoff, or might cause return to base. Remove.	Noise, track path, crew discomfort, poor handling. Visual.	Sheath required only last 53".	SCRAP
		OUTBOARD OF STATION 100				
9.0	Excessive vibration.	Skin and core >25 in.^{2}.	Might cause return to base. Scrap.	Noise, etc. Vibration.		SCRAP
36.0	Excessive vibration.	Skin and core <25 in.^{2} but >1" wide.	Complete mission. Remove.	Noise, etc. Vibration.		SCRAP
1.3	Excessive vibration.	Skin and core inboard of Station 100.	See Note 1.	Visual, vibration.	Preflight insp. reduces prob. of crash.	SCRAP
0.3	Excessive vibration.	Spline fatigue (Crack or kink).	Crack might propagate and cause the effects of Note 2.	Vibration.		SCRAP
3.0	Excessive vibration.	Delamination of skin at T.E.	Might cause return to base.	Vibration, visual.		SCRAP
3.0	Excessive Vibration.	Turbulence due to spline corrosion.	Might cause return to base.	Vibration, visual.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
2.0	Excessive vibration.	Delamination of ext doublers.	See Note 1.	Vibration, visual.	Visual insp and repair reduces probability of crash.	SCRAP
5.8	Excessive vibration.	Retention bushings worn, cracked, or degraded by galvanic action.	Might cause return to base.	Visual.		SCRAP
0.6	Excessive vibration.	Ext doublers cracked or yielded	See Note 1.	Visual, vibration.	Visual insp reduces probability of crash.	SCRAP
1.0	Excessive vibration.	Spar fatigue fail.	Unbalance may cause extensive aircraft damage and personnel injury.	Vibration.		SCRAP
6.0	Excessive vibration.	Skin fatigue crack.	See Note 3.	Vibration, visual.		SCRAP
1.0	Excessive vibration.	Voids within spec, but stiffness reduced by bond fatigue.	Degradation in performance. Return to base.	Vibration, visual.		SCRAP
1.0	Embrittlement.	Skin dented by F.O.'s or abnormal handling.	No mission effect. Scrap blade to prevent fatigue cracks in flight.	Visual.		SCRAP
2.0	Embrittlement.	Spline chips in abnormal handling.	Slight increase in air turbulence. Scrap blade to prevent fatigue cracks in flight.	Visual, vibration.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
124.0	Deterioration.	Crack in skin.	Slight increase in air turbulence. Remove.	Visual, vibration.	Cracks reported as "deterioration" would involve low stress area.	[illegible]-49.6 SCRAP-74.6
20.0	Deterioration.	Spar abraded or eroded.	Slight increase in air turbulence.	Visual, vibration.		ORG.
20.0	Deterioration.	Spline eroded, corroded, or cracked.	Slight degradation in performance due to air turbulence.	Visual, vibration.		SCRAP
13.0	Deterioration.	External doublers, corroded or not parallel to blade.	Corrosion would reduce fatigue life. Roughness would increase air turbulence.	Visual, vibration.		SCRAP
2.4	Bonding delaminated, loose, or poor condition.	Bond failure between abrasion strip and spar >10 in.^{2} single or >30 in.^{2} total.	Degradation in performance might cause return to base. Remove.	Vibration, visual.		SCRAP
27.0	Bonding delaminated, loose, or poor condition.	Skin and core >25 in.^{2}.	Might cause return to base. Scrap.	Vibration, visual.		SCRAP
66.0	Bonding delaminated, loose, or poor condition.	Skin and core <25 in.^{2} but >1" wide.	Complete mission. Remove.	Vibration, visual.		SCRAP
18.0	Bonding delaminated, loose, or poor condition.	Skin and spline.	Might cause return to base.	Vibration, visual.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
14.6	Bonding delaminated, loose, or in poor condition.	Skin and spar.	See Note 3.	Vibration, visual.		SCRAP
3.0	Bonding delaminated, loose, or in poor condition.	Spar and core.	Sufficient unbonding will reduce fatigue life of skin. Scrap.	Visual, span-wise crack in skin at spar edge.		SCRAP
0.3	Bonding delaminated, loose, or in poor condition.	Ext doubler or ext doubler and skin.	See Note 1.	Visual.	Visual insp. prevents large delaminations causing crashes.	SCRAP
0.3	Bonding delaminated, loose, or in poor condition.	Grip or drag plate edge void deeper than .5" at tip.	See Note 1. Scrap.	Visual.	Visual insp. prevents large delaminations causing crashes.	SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Grip plate, less than above.	Slight increase in air turbulence.	Visual.		SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Drag plate, less than above.	No performance effect.	Visual.		SCRAP
10.0	Excessive wear.	Pitted spline.	Slight increase in air turbulence. Reduced fatigue life.	Visual.		SCRAP
5.4	Excessive wear.	Skin.	Slight increase in air turbulence. Reduced fatigue life.	Visual.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
22.4	Excessive wear.	Spar.	Slight increase in air turbulence. Reduced fatigue life.	Visual.		ORG.
0.6	Excessive wear.	Ext doublers or grip plates.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP
55.0	Excessive wear.	Worn retention bushings.	Delay of takeoff or return to base.	Vibration.		SCRAP
20.0	Excessive wear.	Spar abraded or eroded.	Slight increase in air turbulence.	Visual.		ORG.
4.0	Excessive wear.	T.E. eroded or abraded.	Slight increase in air turbulence.	Visual.		SCRAP
1.2	Excessive wear.	Skin near spar abraded, eroded.	Slight increase in air turbulence.	Visual.		SCRAP
10.0	Corroded.	Spar corroded or eroded.	Slight increase in air turbulence.	Visual.		INTER
4.7	Corroded.	Skin.	Slight increase in air turbulence.	Visual.		SCRAP
2.0	Corroded.	Spline.	Slight increase in air turbulence.	Visual.		SCRAP
0.1	Corroded.	Ext doublers, grip,or drag plates.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	EXTERNAL CAUSES OF FAILURE					
30.0	Battle damage. Holes all the way through.	Spar.	See Note 4.	Vibration.		SCRAP
8.0	Battle damage.	Spline.	Might propagate and cause the effects of Note 2.	Vibration.		SCRAP
38.0	Battle damage.	Skin and core >2" dia. or >1" by 4".	See Note 3. Scrap.	Noise, visual, vibration.	Core is not a load carrying part.	SCRAP
185.0	Battle damage.	Skin and core <2" dia. and <1" by 4".	A nonsmooth hole in a high stress location might cause the effects of Note 3. Otherwise will cause return to base.	Noise, visual, vibration.		SCRAP
1.0	Battle damage.	Ext doublers or grip plates.	See Note 1.	Vibration.		SCRAP
370.0	Dented.	Skin or skin and core.	Would cause air turbulence in relation to size and location. Might cause return to base.	Visual, vibration.	See Note 5.	INTER=148 SCRAP=222
5.6	Dented.	Spline > .040" deep.	Fatigue life too limited for safe use.	Visual.		SCRAP
10.0	Dented.	Spline < .040" deep.	Hammer out on aircraft if >.020" deep.	Visual.		ORG.

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
40.0	Dented.	Spar > 1/8" deep in fwd 1-1/2" in the outboard 1/4 of span, or > 1/16" deep elsewhere.	Slight increase in air turbulence. Fatigue life too limited for safe use. Scrap.	Visual.		SCRAP
83.4	Dented.	Spar dented less than above.	No flight effect. Polish out on aircraft.	Visual.		ORG.
4.0	Dented.	Ext doubler, grip, or drag plates > .012" deep.	See Note 1.	Visual.	No repair needed if < .012" deep.	SCRAP
3.0	Foreign object damage.	Nick in spline > .012" deep.	No mission effect. Remove blade. Fatigue life limited.	Visual, vibration.		SCRAP
12.0	Foreign object damage.	Nick in spline < .012" deep and > .008" deep.	Slightly increases air turbulence, but repair should not require removal.	Visual.	No maintenance action required if < .003" deep.	ORG.
30.0	Foreign object damage.	Skin and core crushed or gashed.	Would cause air turbulence in relation to size and location. In worst case, might cause loss of control.	Vibration, visual.	Core is not a principal load carrying member.	SCRAP
46.62	Foreign object damage.	Spar nicked or scratched > 1/8" deep in fwd 1-1/2" in outboard 1/4 of span, or > 1/16" deep elsewhere.	Slight increase in air turbulence. Fatigue life too limited for safe use. Scrap.	Visual.		SCRAP
5.0	Foreign object damage.	Spar nicked or scratched less than above.	No flight effect. Polish out on aircraft depending on depth.	Visual.		ORG.

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
0.02	Foreign object damage.	Spar split in two.	Unbalance may cause extensive aircraft damage and personnel injury.	Loss of control		SCRAP
0.1	Foreign object damage.	Spar gashed or cracked $>2"$ long or all the way through wall.	Likely to propagate and cause extensive aircraft damage and personnel injury.	Vibration.		SCRAP
0.8	Foreign object damage.	Spar gashed or cracked $<2"$ long and not all the way through.	Forced landing or return to base. Scrap.	Vibration.		SCRAP
140.0	Foreign object damage.	Nick or scratch in skin $>.008"$ deep.	See Note 3. Remove blade if polishing out will leave less than .008".	Visual		INTER=56 SCRAP=84
0.06	Foreign object damage.	Ext doublers, grip or drag plates ruptured.	See Note 1. Scrap.	Vibration, visual.		SCRAP
0.6	Foreign object damage.	Ext doublers, grip or drag plates gashed or nicked $>.012"$ deep or cracked.	See Note 1. Scrap.	Vibration, visual.		SCRAP
1.8	Foreign object damage.	Ext doublers, grip,or drag plates nicked or scratched $<.012"$ deep.	May be repaired on aircraft.	Visual.		ORG.
224.0	Punctured through one surface.	Skin and core.	Nonsmooth hole in a high stress location might cause the effects of Note 3.	Visual, vibration.	Smooth hole should have no mission effect.	INTER=89.6 SCRAP=134.4

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
2.0	Punctured through one surface.	Ext doublers, grip plate.	See Note 1. Scrap.	Visual, vibration.		SCRAP
54.0	Punctured through one surface.	Spar.	See Note 4.	Vibration, visual.		SCRAP
129.0	Torn skin and in some case, core also.	Tree strike, handling, tools, F.O.D.	See Note 3.	Vibration, visual.		SCRAP
139.0	Overspeed.	Emergency operation, governor failure, or pilot error.	May cause rupture or crack in retention parts or spar.	Indicator in cockpit if pilot notices.	Specified RPM's for specified short durations require no repair if occur in normal flight attitude under normal g force.	SCRAP
9.3	Crash damage.	One of blades hits ground, water, or dense foreign object.	Fatigue life of any undamaged portions assumed too limited for safe use. Scrap both blades.			SCRAP
1.6	Crash damage only slight or no blade impact.	Inspection of aircraft concludes that blade has been overstressed or overheated past safe use or twisted.	Scrap blade or blades.	Visual.	Blistered paint is not cause for scrappage.	SCRAP
0.4	Crash damage only slight or no blade impact.	Overstress not obvious in on-aircraft inspection.	Fatigue life assumed too limited for safe use.	Visual.		SCRAP

TABLE XV - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
25.0	Overstress.	Aircraft overloaded, out-of-envelope maneuvers.	May cause rupture, crack, or yield of T.E. or retention parts. If no flight effects, fatigue life may be too limited for safe use.	Pilots log.	Specified over-torques for specified short durations require no repair until a specified accumulation.	SCRAP
92.7	Sudden stop.	Blade on or near ground hits an unmovable object.	Scrap both blades.			SCRAP
2221.4	TOTAL					

NOTE 1: Damage may propagate and cause other blade parts to be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.

NOTE 2: Spline rupture in first one-third of span would propagate across chord and cause beam to split, but near tip would allow return to base. Cracks through intermediate span locations would cause forced landings.

NOTE 3: Skin damage might propagate and cause return to base if in outboard two-thirds of span or forced landing if in inboard one-third.

NOTE 4: .30-caliber hits would cause forced landing. Larger projectiles or jagged holes inboard of Station 105 might cause extensive aircraft damage or personnel injury.

NOTE 5: In the outboard 4' of span, smooth dents in skin (not through) that do not produce a void detectable by tapping with a coin and do not cause vibration require no repair. Inboard of this, only dents < .060" deep require no maintenance action.

TABLE XVI. FAILURE MODES AND EFFECTS ANALYSIS, DESIGN 2

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	INHERENT (PART) CAUSES OF FAILURE					
	NON-EDGE VOIDS BETWEEN SURFACES AS FOLLOWS:					
4.7	Excessive vibration. (Vibra. beyond spec., excessive vibra., mismatched, out of adjustment, unable to adjust limits, unbalanced and unstable.)	Nose skin and nose ballast >1" wide at any station.	Delay of takeoff or might cause return to base. Remove.	Noise, track path, crew discomfort, degraded handling. Vibration.		SCRAP
		OUTBOARD OF STATION 100				
6.7	Excessive vibration.	Skin and core >25 in.^{2}	Might cause return to base.	Noise, etc. Vibration.		INTER=2.68 SCRAP=4.02
26.8	Excessive vibration.	Skin and core <25 in.^{2} but >1" wide.	Complete mission. Requires maintenance action.	Noise, etc. Vibration.		INTER
3.0	Excessive vibration.	Aft skin and shear web > 10 in.^{2} single or 30 in.^{2} total.	Might cause return to base. Remove.	Vibration.		SCRAP
3.0	Excessive vibration.	Nose ballast and channel >5" by 2" or >18 in.^{2} total.	Might cause return to base. Remove.	Vibration.		SCRAP
9.2	Excessive vibration.	Skin and shear web >1" by 3" or >30 in.^{2} tot.	Might cause return to base. Remove.	Vibration.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
		INBOARD OF STATION 100				
6.0	Excessive vibration.	Nose skin and shear web > .5" by 1" or > 10 in.^{2} total.	Might cause return to base. Remove.	Vibration.		SCRAP
1.0	Excessive vibration.	Aft skin and shear web > 2 in.^{2} or > 10 in.^{2} total.	Might cause return to base. Remove.	Vibration.		SCRAP
3.0	Excessive vibration.	Nose ballast and channel > .5" by 1.0" or > 5 in.^{2} total.	Might cause return to base. Remove.	Vibration.		SCRAP
0.5	Excessive vibration.	Skin and core.	See Note 1.	Visual, vibration.	Preflight insp. reduces prob. of crashes.	SCRAP
		ALL STATIONS				
0.4	Excessive vibration.	Shear web fatigue fail.	Might cause forced landing. Scrap.	Vibration.		SCRAP
0.1	Excessive vibration.	Spline fatigue (split or cracked).	See Note 2.	Vibration, visual.		SCRAP
2.0	Excessive vibration.	Delamination of skin at T.E. or spline itself.	Might cause return to base.	Vibration, visual.		SCRAP
2.0	Excessive vibration.	Delamination of ext doublers.	See Note 1.	Vibration, visual.	Visual insp. and repair reduces prob. of crash.	SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
5.2	Excessive vibration.	Retention bushings worn, cracked, or degraded by galvanic action.	Might cause return to base.	Vibration.		SCRAP
2.0	Excessive vibration.	Nose ballast channel cracks or bond to nose skin fails.	Might cause return to base.	Vibration.		SCRAP
0.6	Excessive vibration.	Ext. doublers cracked or yielded (fatigue).	See Note 1.	Visual, vibration.	Visual insp. reduces prob. of crash.	SCRAP
0.4	Excessive vibration.	Nose skin fatigue failure.	Unbalance may cause extensive aircraft damage and personnel injury.	Vibration, visual.		SCRAP
4.0	Excessive vibration.	Aft skin fatigue crack.	See Note 3.	Visual, vibration.		INTER
3.0	Excessive vibration.	Voids within spec. but stiffness reduced by bond fatigue.	Degradation in performance. Return to base.	Vibration.		SCRAP
8.0	Embrittlement.	Skin dented by F.O.'s and normal handling.	No mission effect. Scrap blade to prevent fatigue cracks in flight.	Visual.		SCRAP
0.8	Embrittlement.	Spline chips in normal handling.	Slight degradation in performance.	Visual, vibration.		SCRAP
92.0	Deterioration.	Crack in aft skin.	Slight degradation in performance.	Visual, vibration.	Cracks reported as "Deterioration" would involve low stress areas.	INTER

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
8.0	Deterioration.	Spline delaminated.	Slight degradation in performance due to air turbulence.	Visual, vibration.		SCRAP
13.0	Deterioration.	Ext doublers corroded or not smooth after repair.	Corrosion would reduce fatigue life. Roughness would increase air turbulence.	Visual, vibration.		SCRAP
0.8	Deterioration.	Nose skin eroded, or abraded.	See Note 4.	Vibration, visual.	See Note 5.	ORG.
2.0	Bonding delaminated, loose, or in poor condition.	Bond failure between aft skin and shear web >10 in.^{2} single or >30 in.^{2} total.	See Note 3.	Vibration, visual.		SCRAP
0.5	Bonding delaminated, loose, or in poor condition.	Stiffener and shear web.	If ground forces cause spar buckling, the blade may be removed or scrapped.	Visual if spar buckles.	Spar buckling degrades only the appearance and performance of blade.	SCRAP
35.0	Bonding delaminated, loose, or in poor condition.	Skin and core >25 in.^{2}	Might cause return to base.	Vibration, visual.		INTER=14 SCRAP=21
80.0	Bonding delaminated, loose, or in poor condition.	Skin and core <25 in.^{2} but $>1"$ wide.	Complete mission.	Vibration, visual.		INTER
10.0	Bonding delaminated, loose, or in poor condition.	Skin and spline.	Might cause return to base.	Vibration, visual.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
0.3	Bonding delaminated, loose, or in poor condition.	Ext doubler or ext doubler and skin.	See Note 1.	Vibration, visual.	Visual insp prevents large delaminations from causing crashes.	SCRAP
0.3	Bonding delaminated, loose, or in poor condition.	Grip or drag plate edge void deeper than .5" at tip.	See Note 1. Scrap.	Vibration, visual.	Visual insp prevents large delaminations from causing crashes.	SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Grip plate, less than above.	Slight increase in air turbulence.	Visual.		SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Drag plate, less than above.	No performance effect.	Visual.		SCRAP
12.9	Bonding delaminated, loose, or in poor condition.	Nose skin and shear web.	Propagation of bond failure may cause nose skin to shear.	Vibration, tapping during periodic inspect., visual.		SCRAP
4.0	Bonding delaminated, loose, or in poor condition.	Shear web and core.	Sufficient unbonding will reduce fatigue life of skin. Scrap.	Visual, spanwise crack in skin at edge of shear web.		SCRAP
0.6	Excessive wear.	Pitted ext doublers or grip plates.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
55.0	Excessive wear.	Worn retention bushings.	Delay of takeoff or return to base.	Vibration.		SCRAP
5.0	Excessive wear.	Nose skin eroded or abraded.	See Note 4.	Vibration, visual.	See Note 5.	ORG.
3.0	Excessive wear.	Spline eroded or abraded.	Increase in air turbulence causes slight degradation in performance. Decrease in life.	Visual, vibration.		SCRAP
0.6	Excessive wear.	Aft skin near nose eroded, abraded, or uneven.	Increase in air turbulence causes slight degradation in performance. Decrease in life.	Visual, vibration.		SCRAP
3.0	Corroded.	Nose skin eroded.	See Note 4.	Vibration, visual.	See Note 5.	INTER.
2.0	Corroded.	Spline eroded.	Decrease in fatigue life. Slight decrease in performance.	Visual, vibration.		SCRAP
1.5	Corroded.	Aft skin near nose eroded.	Decrease in fatigue life. Slight decrease in performance.	Visual.		SCRAP
0.1	Corroded.	Ext doubler or grip or drag plates corroded.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP
	EXTERNAL CAUSES OF FAILURE					
28.0	Battle damage. Holes all the way through.	Nose skin or nose skin and shear web.	See Note 6. Scrap.	Vibration.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
10.0	Battle damage. Holes all the way through.	Spline.	See Note 8.	Vibration, visual.		SCRAP
20.0	Battle damage. Holes all the way through.	Aft skin and core.	See Note 3.	Noise, visual.		SCRAP
49.0	Battle damage. Holes all the way through.	Aft skin and core small enough for local repair.	Slight increase in air turbulence.	Noise, visual.		SCRAP
1.0	Battle damage. Holes all the way through.	Ext doublers or grip plates.	See Note 1.	Noise, visual.		SCRAP
21.0	Battle damage. Holes all the way through.	Shear web and aft skin.	See Note 6. Scrap.	Noise, visual.	Crack propagation would slow at interface with nose skin.	SCRAP
4.0	Dented.	Ext doubler or grip plate > .012" deep.	See Note 1.	Visual.	No repair needed if < .012" deep.	SCRAP
300.0	Dented.	Skin or skin and core.	Degradation in performance depends on size and location. See Note 9.	Visual, vibration.	Reduction in fatigue life is not severe if dent is smooth.	INTER= 180 SCRAP= 120
10.0	Dented.	Skin over shear web crushed.	No mission effect. Determine if there is rough dent in shear web.	Visual.		SCRAP
20.0	Dented.	Skin over shear web (not crushed).	No repair required. Slight increase in air turbulence.	Visual.	Damage will not propagate.	ORG.

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
30.0	Dented.	Nose skin, or nose skin and shear web, or shear web under aft skin, rough dent or dent $>$ .010" deep.	No mission effect. Unless dent is superficial, fatigue life will be too limited for safe use.	Visual.		SCRAP
54.0	Dented.	Same as above but smooth and $<$ .010" deep.	No flight effect. Polish out on aircraft, or use as is, depending on depth.	Visual.		ORG.
16.0	Dented	Spline or aft skin and spline.	Slight increase in air turbulence. Repair if flight effect.	Visual.	Damage will not propagate at fast rate.	ORG.
10.0	Foreign object damage.	Nick or cut in spline.	Increase in air turbulence depends on depth and span location.	Visual, vibration.	Damage will not propagate at fast rate.	ORG. =4 SCRAP=6
55.0	Foreign object damage.	Core crushed or gashed.	Would cause air turbulence in relation to size and location. In worst case,might cause loss of control.	Vibration, visual.	Core is not a principal load carrying part.	INTER=11 SCRAP=44
100.0	Foreign object damage.	Nick or scratch in nose skin or shear web $>$ .005" deep.	No mission effect. Fatigue life too limited for safe use. Scrap.	Visual.		SCRAP
6.0	Foreign object damage.	Nick or scratch in nose skin or shear web $<$ .005" deep.	No flight effect. Polish out on aircraft.	Visual.		ORG.
0.02	Foreign object damage.	Nose skin split in two.	Unbalance may cause extensive aircraft damage and personnel injury.	Loss of control.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
0.06	Foreign object damage.	Nose skin cracked > 2" long and all the way through.	See Note 7.	Loss of control.	301 stainless steel has good notch toughness.	SCRAP
1.0	Foreign object damage.	Nose skin cracked < 2" long or not all the way through.	Might cause forced landing. Scrap.	Vibration, visual.		SCRAP
0.1	Foreign object damage.	Shear web cracked, cut > 3.5" long.	Might cause forced landing. Scrap.	Vibration.		SCRAP
1.0	Foreign object damage.	Shear web cracked or cut < 3.5" long.	Might cause return to base. Scrap.	Vibration.		SCRAP
52.0	Foreign object damage.	Nick or scratch in aft skin repairable locally.	Slight increase in air turbulence. Scrap.	Visual.		SCRAP
52.0	Foreign object damage.	Nick or scratch in skin repairable locally.	Decrease in fatigue life.	Visual.		ORG.
0.06	Foreign object damage.	Ext doublers, grip,or drag plates ruptured.	See Note 1. Scrap.	Vibration, visual.		SCRAP
0.6	Foreign object damage.	Ext doublers, grip,or drag plates gashed or nicked >.012" deep, or cracked.	See Note 1. Scrap.	Vibration, visual.		SCRAP
6.0	Foreign object damage.	Ext doublers, grip,or drag plates nicked or scratched < .012 deep.	May be repaired on aircraft.	Visual.		ORG.
26.6	Punctured through one surface.	Nose skin or nose skin and shear web.	See Note 6. Scrap.	Vibration.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
183.0	Punctured through one surface.	Aft skin and core.	See Note 3.	Visual, vibration.		INTER
2.0	Punctured through one surface.	Ext doubler or grip plate.	See Note 1.	Vibration, visual.		SCRAP
14.0	Punctured through one surface.	Shear web and aft skin.	See Note 6. Scrap.	Vibration.		SCRAP
96.0	Torn skin and in some cases, core also.	Tree strike, handling, tools, F.O.D.	See Note 3.	Vibration.	Cross-ply G.F.R.P. resists tearing forces well.	INTER = 38.4 SCRAP = 57.6
126.4	Overspeed.	Emergency operation, governor failure, or pilot error.	May cause rupture or crack in retention parts, nose skin, or shear web. If no flight effects, the need to remove, inspect, and possibly scrap depend on extent of overspeed.	Indicator in cockpit if pilot notices.	Specified RPM's for specified short durations require no repair if occur in normal flight attitude under normal g forces.	SCRAP
9.3	Crash damage.	One of blades hits ground, water, or dense foreign object.	Fatigue life of any undamaged portions assumed too limited for safe use. Scrap both blades.	Visual.		SCRAP

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
1.3	Crash with only slight or no blade impact.	Inspection of aircraft concludes that blade has been overstressed or overheated past safe use, or twisted.	Scrap blade or blades.	Visual.		SCRAP
0.7	Crash with only slight or no blade impact.	Overstress not obvious in on-aircraft inspection.	Fatigue life assumed too limited for safe use.	Visual.		SCRAP
22.6	Overstress.	Aircraft overloaded, out-of-envelope maneuvers.	May cause rupture, crack, or yield of T.E. or retention parts. If no flight effects, fatigue life may be too limited for safe use. Pilots log must be compared with inspection instructions. If instruction is not to scrap, retention bolts should be removed and inspected. If bolt or material around bushing has yielded, scrap blade.	Pilots log.	Specified over torques for specified short durations require no repair until a specified accumulation.	SCRAP
92.7	Sudden stop.	Blade on or near ground hits an unmovable object.	Scrap both blades.			SCRAP
1845.84	TOTAL					

TABLE XVI - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				

NOTE 1: Damage may propagate and cause other blade parts to be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.

NOTE 2: Spline rupture in first two-thirds of span would propagate across skin to spar, and cause a forced landing. Rupture near tip would allow return to base.

NOTE 3: Skin damage might propagate and cause return to base if in outboard two-thirds of span or forced landing if in inboard one-third.

NOTE 4: Slight shift in weight distribution and increase in air turbulence. May not match a less eroded blade.

NOTE 5: Not a safety hazard. Erosion is greatest near tip where strength-to-stress margin is highest.

NOTE 6: .30-caliber bullet holes would cause return to base. Larger projectiles or jagged holes inboard of Station 105 would cause forced landing.

NOTE 7: Damage likely to propagate and cause extensive aircraft damage and personnel injury.

NOTE 8: In outboard portion of span, likely to cause rupture with effect of Note 2. Inboard slight degradation of performance and reduced fatigue life.

NOTE 9: Smooth dents $<$.10" deep require no repair if not crazed.

TABLE XVII. FAILURE MODES AND EFFECTS ANALYSIS, DESIGN 3

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	INHERENT (PART) CAUSES OF FAILURE					
	NON-EDGE VOIDS BETWEEN SURFACES AS FOLLOWS:					
2.0	Excessive vibration (Vibration beyond spec., excessive vibra., mismatched, out of adjustment, unable to adjust limits, unbalanced and unstable.)	Shear web and core.	Might cause return to base. Scrap.	Noise, track path, crew discomfort, degraded handling.		SCRAP
2.0	Excessive vibration.	Abrasive strip and spar > 1" wide, outboard of Station 100.	Might cause return to base.	Noise, track path, crew discomfort, degraded handling.		SCRAP
8.0	Excessive vibration.	Skin and core > 25 in^2 outboard of Station 100.	Might cause return to base.	Noise, track path, crew discomfort, degraded handling.		INTER = 3.2 SCRAP = 4.8
32.0	Excessive vibration.	Skin and core < 25 in^2 but < 1" wide outboard of Station 100.	Complete mission. Requires maintenance action.	Noise, track path, crew discomfort, degraded handling.		INTER
1.2	Excessive vibration.	Skin and core inboard of Station 100.	See Note 1.	Visual, vibration.	Preflight insp. reduces probability of crashes.	SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
3.0	Excessive vibration.	Corrosion of spline.	Might crack, propagate, and cause effects of Note 2.	Vibration, visual.		SCRAP
0.3	Excessive vibration.	Spline fatigue (kinked or cracked).	Crack might propagate and cause effects of Note 2.	Vibration, visual.		SCRAP
2.7	Excessive vibration.	Delamination of skin at T.E. or at spar.	Might cause return to base.	Vibration, visual.		SCRAP
2.0	Excessive vibration.	Delamination of ext doublers.	See Note 1.	Visual, vibration.	Visual inspection reduces probability of crash.	SCRAP
5.8	Excessive vibration.	Retention bushings worn, cracked, or degraded by galvanic action.	Might cause return to base.	Vibration.		SCRAP
0.6	Excessive vibration.	Ext doublers cracked or yielded.	See Note 1.	Visual, vibration.	Visual inspection reduces probability of crash.	SCRAP
1.0	Excessive vibration.	Spar fatigue failure.	Unbalance may cause extensive aircraft damag[illegible] and personnel injury.	[illegible]bration, [illegible]al.		SCRAP
3.0	Excessive vibration.	Skin fatigue crack.	See Note 3.	[illegible]ion, [illegible].	Skin is not a structural part.	INTER
0.9	Excessive vibration.	Voids within spec., but stiffness reduced by bond fatigue.	Degradation in perfo[illegible]mance. Return to base.	[illegible]tion, [illegible]ual.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
11.5	Excessive vibration.	Shear web bond to spar or to spline fails or web cracks.	See Note 4.	Vibration.	Damage will not propagate into other members.	SCRAP
10.0	Embrittlement.	Skin dented by F.O.'s and normal handling.	No mission effect. Scrap blade to prevent fatigue cracks in flight.	Visual.		SCRAP
2.0	Embrittlement.	Spline chips in normal handling.	Slight degradation in performance.	Visual, vibration.		SCRAP
62.0	Deterioration.	Crack in skin.	See Note 3.	Visual, vibration.	Skin is not a structural part.	INTER
20.0	Deterioration.	Spline cracked or abraded.	Crack might propagate and cause the effects of Note 2.	Visual, vibration.		SCRAP
13.0	Deterioration.	Ext doublers corroded or not smooth.	Corrosion would reduce fatigue life. Roughness would increase air turbulence.	Visual, vibration.		SCRAP
2.0	Deterioration.	Spar abraded. or eroded.	See Note 5.	Vibration, visual.	See Note 5.	ORG.
3.0	Bonding delaminated, loose, or in poor condition.	Bond failure between shear web and core.	Might cause return to base. Scrap.	Vibration.		SCRAP
11.6	Bonding delaminated, loose, or in poor condition.	Shear web and spar or spline.	See Note 4.	Vibration.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
24.0	Bonding delaminated, loose, or in poor condition.	Skin and core > 25 in.^{2}	Might cause return to base. Danger of skin tearing.	Vibration, visual.	Blade stiffness will not decrease significantly.	INTER = 9.6 SCRAP = 14.4
60.0	Bonding delaminated, loose, or in poor condition.	Skin and core < 25 in.^{2} but $> 1"$ wide.	Complete mission.	Visual, vibration.	Blade stiffness will not decrease significantly.	INTER
30.0	Bonding delaminated, loose, or in poor condition.	Skin and spline or skin and spar.	Might cause return to base. Danger of tearing on L.E.	Visual, vibration.	Skin is non-structural part.	SCRAP
0.3	Bonding delaminated, loose, or in poor condition.	Ext doubler or ext doubler and skin.	See Note 1.	Visual, vibration.	Visual inspection reduces probability of crash.	SCRAP
0.3	Bonding delaminated, loose, or in poor condition.	Grip or drag plate edge void deeper than .5" at tip.	See Note 1. Scrap.	Visual, vibration.	Visual inspection reduces probability of crash.	SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Grip plate, less than above.	Slight increase in air turbulence.	Visual.		SCRAP
1.2	Bonding delaminated, loose, or in poor condition.	Drag plate, less than above.	No performance effect. Fatigue life reduced.	Visual.		SCRAP
2.4	Bonding delaminated, loose, or in poor condition.	Abrasive strip and spar $> 1"$ wide.	Might cause return to base.	Vibration.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
0.6	Excessive wear.	Pitted ext doublers or grip plates.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP
10.0	Excessive wear.	Spline.	Slight increase in air turbulence. Reduced life.	Visual.		SCRAP
22.4	Excessive wear.	Spar.	Slight increase in air turbulence. Reduced life.	Visual.		ORG.
55.0	Excessive wear.	Worn retention bushings.	Delay of takeoff or return to base.	Vibration.		SCRAP
20.0	Excessive wear.	Spar abraded or eroded.	See Note 5.	Vibration, visual.	See Note 5.	ORG.
4.0	Excessive wear.	Spline eroded or abraded.	Increase in air turbulence causes slight degradation in performance. Decrease in fatigue life.	Visual, vibration.		SCRAP
1.2	Excessive wear.	Skin near spar eroded or abraded.	Erosion increases danger of skin tearing. Unevenness slightly increases air turbulence.	Visual, vibration.	Blade stiffness does not depend on skin.	SCRAP
10.0	Corroded.	Spar corroded or eroded.	See Note 5.	Vibration, visual.	See Note 5.	INTER
2.0	Corroded.	Spline eroded.	Decrease in fatigue life. Slight decrease in performance.	Visual, vibration.		SCRAP
1.0	Corroded.	Skin near spar eroded.	Danger of tearing.	Visual.	Skin is non-structural.	SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
0.1	Corroded.	Ext doubler or grip or drag plates corroded.	Reduced fatigue life. Safety hazard.	Visual.		SCRAP
	EXTERNAL CAUSES OF FAILURE					
30.0	Battle damage. Holes all the way through.	Spar.	See Note 7.	Vibration.		SCRAP
223.0	Battle damage. Holes all the way through.	Core and skin and shear web.	Reduction in stiffness, but mission could be completed. Scrap.	Noise, visual.	Damage propagation is slow as stress level is low.	SCRAP
8.0	Battle damage. Holes all the way through.	Spline.	Damage might propagate and result in the effects of Note 2.	Vibration, visual.		SCRAP
1.0	Battle damage.	Ext doublers or grip plates.	See Note 1.	Vibration, handling.		SCRAP
600.0	Dented.	Skin or skin and core.	Degradation in performance depends on size and location.	Visual, vibration.	Reduction in fatigue life is not significant if dent is smooth.	INTER = 360 SCRAP = 240
40.0	Dented.	Spar > 1/8" deep in forward 1-1/2" in outboard 1/4 of span or > 1/16" deep elsewhere.	Slight increase in air turbulence. Fatigue life too limited for safe use. Scrap.	Visual.		SCRAP

TABLE XVII - Co tinued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
83.4	Dented.	Spar dented less than above.	No flight effect. Polish out on aircraft.	Visual.		ORG.
5.6	Dented.	Spline > .040" deep.	Slight increase in air turbulence. Fatigue life too limited for safe use.	Visual, vibration.		SCRAP
10.0	Dented.	Spline < .040" deep.	Hammer out on aircraft if >.020" deep.	Visual.		ORG.
4.0	Dented.	Ext doubler or grip plate > .012" deep.	See Note 1.	Visual.	No repair needed if < .012 deep.	SCRAP
3.0	Foreign object damage.	Nick in spline > .120" deep.	No mission effect. Remove blade. Fatigue life should be evaluated.	Visual, vibration.		SCRAP
12.0	Foreign object damage.	Nick in spline < .120" deep and > .008" deep.	Slightly increases air turbulence but repair should not require removal.	Visual.	No maintenance action required if < .008" deep.	ORG.
120.0	Foreign object damage.	Core crushed or gashed.	Would cause air turbulence in relation to size and location. In worst case, might cause loss of control.	Vibration, visual.	Core is not a principal load carrying member.	INTEP=24 SCRAP=96
46.62	Foreign object damage.	Spar nicked or scratched > 1/8" deep in forward 1-1/2" in outboard 1/4 of span, or > 1/16" deep elsewhere.	Slight increase in air turbulence. Fatigue life too limited for safe use. Scrap.	Visual.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
5.0	Foreign object damage.	Spar nicked or scratched less than above.	No flight effect. Polish out on aircraft depending on depth.	Visual.		ORG.
0.02	Foreign object damage.	Spar split in two.	Unbalance may cause extensive aircraft damage and personnel injury.	Loss of control.		SCRAP
0.1	Foreign object damage.	Spar gashed or cracked > 2" long and all the way through wall.	Likely to propagate and cause extensive aircraft damage and personnel injury.	Vibration.		SCRAP
0.8	Foreign object damage.	Spar gashed or cracked < 2" long or not all the way through.	Forced landing or return to base. Scrap.	Vibration.		SCRAP
45.0	Foreign object damage.	Nick or scratch in skin.	Slight increase in air turbulence. Repair on aircraft or locally.	Visual.	Repair does not require patch.	ORG.
1.8	Foreign object damage.	Ext doublers, grip or drag plates nicked or scratched < .012 deep.	May be repaired on aircraft.	Visual.		ORG.
0.06	Foreign object damage.	Ext doublers, grip or drag plates ruptured.	See Note 1. Scrap.	Vibration, visual.		SCRAP
0.6	Foreign object damage	Ext doublers, grip or drag plates gashed or nicked > .012" deep, or cracked.	See Note 1. Scrap.	Vibration, visual.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
54.0	Punctured through one surface.	Spar.	See Note 7.	Vibration, visual.		SCRAP
350.0	Punctured through one surface.	Skin and core (no damage to shear web).	Slight increase in air turbulence.	Visual.	Repair does not require skin patch.	INTER
2.0	Punctured.	Ext doubler or grip plate.	See Note 1.	Vibration, visual.		SCRAP
200.0	Torn skin and in some cases, core also.	Tree strike, handling, tools, F.O.D.	Wind and pressure change may propagate tear to point of loss of control.	Vibration, visual.	Blade stiffness does not depend on skin. Light stress on skin.	INTER = 80 SCRAP = 120
139.0	Overspeed.	Emergency operation, governor failure, or pilot error.	May cause rupture or crack in retention parts and spar.	Indicator in cockpit if pilot notices.	Specified RPM's for specified short durations require no repair if occur in normal flight attitude under normal "g" forces.	SCRAP
9.3	Crash damage.	One of blades hits ground, water, or dense foreign object.	Fatigue life of any undamaged portions assumed too limited for safe use. Scrap both blades.	Visual.		SCRAP

TABLE XVII - Continued

NO. FAILS IN 10^6 BLADE HR	MODE OF FAILURE		EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION
	APPEARANCE OR BEHAVIOR	DESCRIPTION AND/OR LOCATION				
1.6	Crash damage with only slight or no blade impact.	Inspection of aircraft concludes that blade has been overstressed or overheated past safe use, or is twisted.	Scrap blade or blades.	Visual.		SCRAP
0.4	Crash damage with only slight or no blade impact.	Overstress not obvious in on-aircraft inspection.	Retention bolts must be removed; bushing area and root end inspected for indication of overstress.	Visual.		SCRAP
25.0	Overstress.	Aircraft overloaded, out-of-envelope maneuvers.	May cause rupture, crack, or yield of T.E. or retention parts. Fatigue life assumed too limited for safe use.	Pilot's log.	Specified over torques for specified short durations require no action until a specified accumulation.	SCRAP
92.7	Sudden stop.	Blade on or near ground hits an unmovable object.	Scrap both blades.	Visual.		SCRAP
2559.3	TOTAL					

TABLE XVII - Continued

NO. FAILS IN 10^5 BLADE HR	MODE OF FAILURE: APPEARANCE OR BEHAVIOR	MODE OF FAILURE: DESCRIPTION AND/OR LOCATION	EFFECT & CONSEQUENCES	METHOD OF DETECTION	COMPENSATING PROVISIONS	DISPOSITION

NOTE 1: Damage may propagate and cause other blade parts to be overstressed to fail point. Reduced blade stiffness may cause vibration and out-of-track to point of loss of control.

NOTE 2: Spline rupture in first one-third of span would propagate across chord and cause beam to split. Crack near tip would allow return to base. Cracks through intermediate span locations would cause forced landings.

NOTE 3: Blade stiffness does not depend on skin. Wind and aerodynamic pressure changes, however, may propagate crack and tear skin to point of loss of control.

NOTE 4: Shear web failure in first one-third of span would cause forced landing. In outboard two-thirds, would cause return to base.

NOTE 5: Slight shift in weight distribution and increase in air turbulence. May not match a less eroded blade.

NOTE 6: Not a safety hazard. Erosion is greatest near tip where strength to stress margin is highest.

NOTE 7: .30-caliber bullet holes would cause forced landings. Larger projectiles or jagged holes inboard of Station 105 might propagate and cause extensive aircraft damage and personnel injury.

APPENDIX II

FIELD REPAIR ANALYSIS

Tables XVIII through XXII present the analysis of aircraft downtime and organizational or intermediate level repair labor required to perform each repair indicated in the failure modes and effects analyses for each of the blades. The repair kits, which provide the bases for material costs, are also presented in these tables.

These aircraft and labor times and material costs are used in the life-cycle cost analysis.

TABLE XVIII. FIELD REPAIR ANALYSIS, CURRENT BLADE (REPAIRABLE)

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
60.0	Crack in skin.	5	Patch small skin area.	3.75		1.6	3
134.4	Dented skin or dented skin and core.	5	Patch small skin area.	3.75		1.6	3
10.0	Dented spline < .040" deep.	1	Blend/refinish.	0.6	0.6		1
40.0	Dented abrasive strip, 18.8 CRES.	2	Restore profile.	0.8	0.8		1
12.0	F.O.D. - Nick in spline < .120" deep > .008" deep.	1	Blend/refinish.	0.7	0.7		1
6.0	F.O.D. - Nick or scratch in abrasive strip < .012" deep.	1	Blend/refinish.	0.4	0.4		1
56.27	F.O.D. - Nick or scratch in skin > .008" deep.	5	Patch small skin area.	3.75		1.6	3
1.8	F.O.D. - External doublers, grip or drag plates nicked or scratched < .012" deep.	1	Blend/refinish.	0.4	0.4		1

TABLE XIX. FIELD REPAIR ANALYSIS, CURRENT BLADE (EXPENDABLE)

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
60.0	Crack in skin.	5	Patch small skin area.	3.75		1.6	3
134.4	Dented skin or dented skin and core.	5	Patch small skin area.	3.75		1.6	[illegible]
10.0	Dented spline < .040"deep.	1	Blend/refinish.	2.5	0.6		1
40.0	Dented abrasive strip, 18.8 CRES.	2	Restore profile.	4.7	0.8		1
12.0	F.O.D. - Nick in spline < .120" deep but > .008" deep.	1	Blend/refinish.	2.6	0.7		1
6.0	F.O.D. - Nick or scratch in abrasive strip < .012" deep.	1	Blend/refinish.	2.3	0.4		1
56.27	F.O.D. - Nick or scratch in skin > .008" deep.	5	Patch small skin area.	3.75		1.6	3
1.8	F.O.D. - External doublers, grip or drag plates nicked or scratched < .012" deep.	1	Blend/refinish.	2.3	0.4		1
96.0	Puncture through one surface of skin and core.	5	Patch small skin area.	3.75		1.6	3

TABLE XX. FIELD REPAIR ANALYSIS, DESIGN 1

RATE/ 10^6 HR	FAILURES DESCRIPTION	NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
49.6	Crack in skin.	5	Patch small skin area.	3.75		1.6	3
20.0	Abraded or eroded spar.	1	Blend/refinish.	3.1	1.2		1
22.4	Wear on spar.	1	Blend/refinish.	3.1	1.2		1
20.0	Abraded or eroded spar.	1	Blend/refinish.	3.1	1.2		1
10.0	Corroded or eroded spar.	1	Blend/refinish.	3.75		2.4	1
148.0	Dented skin or dented skin and core.	5	Patch small skin area.	3.75		1.6	3
10.0	Dented spline $<.040"$ deep.	1	Blend/refinish.	2.5	0.6		1
83.4	Dented spar $<.125"$ deep in forward 1.5" in the outboard 1/4 of span, or $<.062"$ deep elsewhere.	2	Restore profile.	4.7	0.8		1
12.0	F.O.D. - Nick in spline $<.120"$ deep and $>.008"$ deep.	1	Blend/refinish.	2.6	0.7		1
5.0	F.O.D. - Nicked or scratched spar $<.125"$ deep in forward 1.5" in outboard 1/4 of span, or $<.062"$ elsewhere.	2	Restore profile.	4.7	0.8		1
56.0	F.O.D. - Nick or scratch in skin $>.008"$ deep.	5	Patch small skin area.	3.75		1.6	3
1.8	F.O.D. - External doublers, grip, or drag plates nicked or scratched $<.012"$ deep.	1	Blend/refinish.	2.3	0.4		1
89.6	Puncture through one surface of skin and core.	5	Patch small skin area.	3.75		1.6	3

TABLE XXI. FIELD REPAIR ANALYSIS, DESIGN 2

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
2.68	Nonedge void between skin and core > 25 sq. in.	4	Patch large skin area.	3.75		3.8	2
26.8	Nonedge void between skin and core < 25 sq. in. but > 1" wide.	3	Patch small skin area.	3.75		2.0	2
4.0	Cracked aft skin.	3	Patch small skin area.	3.75		1.8	2
92.0	Cracked aft skin.	3	Patch small skin area.	3.75		1.8	2
0.8	Eroded or abraded nose skin.	1	Blend/refinish.	0.6	0.6		-
14.0	Delaminated bond between skin and core > 25 sq. in.	4	Patch large skin area.	3.75		3.8	2
80.0	Delaminated bond between skin and core < 25 sq. in. but > 1" wide.	3	Patch small skin area.	3.75		2.0	2
5.0	Eroded or abraded nose skin.	1	Blend/refinish.	0.6	0.6		-
3.0	Corroded or eroded nose skin.	1	Blend/refinish.	3.75		2.4	1
180.0	Dented skin or dented skin and core.	3 7	Patch small skin area. Fill small core area.	3.75		2.2	2
20.0	Dented skin over shear web (not crushed)	2	Restore profile.	4.9	1.0		1
54.0	Dented nose skin or nose skin and shear web or shear web under aft skin, smooth dent < .010" deep.	1	Blend/refinish.	2.3	0.4		1
16.0	Dented spline or aft skin and spline.	1	Blend/refinish.	2.5	0.6		1

TABLE XXI - Continued

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
4.0	F.O.D. - Nick or cut in spline.	1	Blend/refinish.	2.6	0.7		1
11.0	F.O.D. - Crushed or gashed core.	4 8	Patch large skin area. Fill large core area.	3.75		4.4	2
6.0	F.O.D. - Nick or scratch in nose skin or shear web < .005" deep.	1	Blend/refinish.	0.4	0.4		-
52.0	F.O.D. - Nick or scratch in skin.	2	Restore profile.	4.9	1.0		1
6.0	F.O.D. - Nicked or scratched external doublers or drag plates < .012" deep.	1	Blend/refinish.	2.3	0.4		1
183.0	Puncture through one skin and core.	3 7	Patch small skin area. Fill small core area.	3.75		2.2	2
38.4	F.O.D. - Tree strike, handling, etc., cause torn skin or torn skin and core.	4 8	Patch large skin area. Fill large core area.	3.75		4.4	2

TABLE XXII. FIELD REPAIR ANALYSIS, DESIGN 3

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
3.2	Nonedge void between skin and core > 25 sq. in.	4	Patch large skin area.	3.75		3.8	2
32.0	Nonedge void between skin and core < 25 sq. in. but > 1" wide.	3	Patch small skin area.	3.75		2.0	2
3.0	Cracked skin.	3	Patch small skin area.	3.75		1.8	2
62.0	Cracked skin.	3	Patch small skin area.	3.75		1.8	2
2.0	Abraded or eroded spar.	1	Blend/refinish.	3.1	1.2		1
9.6	Delaminated bond between skin and core > 25 sq. in.	4	Patch large skin area.	3.75		3.6	2
60.0	Delaminated bond between skin and core < 25 sq. in. but > 1" wide.	3	Patch small skin area.	3.75		2.0	2
22.4	Wear on spar.	1	Blend/refinish.	3.1	1.2		1
20.0	Abraded or eroded spar.	1	Blend/refinish.	3.1	1.2		1
10.0	Corroded or eroded spar.	1	Blend/refinish.	3.75		2.4	1
360.0	Dented skin or dented skin and core.	3 7	Patch small skin area. Fill small core area.	3.75		2.2	2
83.4	Dented spar <.125" deep in forward 1.5" in outboard 1/4 of span, or <.062" deep elsewhere.	2	Restore profile.	4.7	0.8		1
10.0	Dented spline <.040" deep.	1	Blend/refinish.	2.5	0.6		1

TABLE XXII - Continued

RATE/ 10^6 HR	FAILURES DESCRIPTION	REPAIR SCHEMES NO.	REPAIR SCHEMES DESCRIPTION	A/C DOWN-TIME (HR)	ORG REPAIR TIME (HR)	INTER REPAIR TIME (HR)	KIT NO.
12.0	F.O.D. - Nick in spline $<$.120" deep and $>$.008" deep.	1	Blend/refinish.	2.6	0.7		1
24.0	F.O.D. - Crushed or gashed core.	4 8	Patch large skin area. Fill large core area.	3.75		4.4	2
5.0	F.O.D. - Nicked or scratched spar $<$.125" deep in forward 1.5" in outboard 1/4 of span, or $<$.062" deep elsewhere.	2	Restore profile.	4.7	0.8		1
45.0	F.O.D. - Nick or scratch in skin.	2	Restore profile.	4.9	1.0		1
1.8	F.O.D. - Nicked or scratched external doublers, grip or drag plates $<$.012" deep.	1	Blend/refinish.	2.3	0.4		1
350.0	Puncture through one skin and core (no damage to shear web)	3 7	Patch small skin area. Fill small core area.	3.75		2.2	2
80.0	F.O.D. - Tree strike, handling, etc., causes torn skin and in some cases core also.	4 8	Patch large skin area. Fill large core area.	3.75		4.4	2

APPENDIX III

STANDARD REPAIR PROCEDURES

INDEX

NOTE: A combination of two or more of the above procedures may be required to accomplish repair of a single damage incident.

Blend Repair Not Requiring Restoration of Profile.

REPAIR PROCEDURE NO. 1

1. Blend scratch, nick, gouge, chip, etc., using die, file and abrasive paper.

2. Using suitable means, measure depth of rework. Continue with step 3 below only if depth of rework is within allowable limits and is shallow enough not to require restoration of original profile. If profile must be restored, accomplish Repair Procedure No. 2.

3. Clean reworked area using MEK solvent and cheesecloth.

4. Apply brushable alodine or cadmium, respectively, to reworked aluminum or steel. Omit this step if material being reworked is stainless steel, titanium, or fiberglass.

5. Touch up repair area using aerosol cans of zinc chromate primer, black paint, and brown paint, as required.

Blend Repair Requiring Restoration of Profile.

REPAIR PROCEDURE NO. 2

1. Blend scratch, nick, gouge, chip, etc., using die, file and abrasive paper.

2. Using suitable means, measure depth of rework. Continue with step 3 below only if depth of rework is within allowable limits.

3. Clean reworked area using MEK solvent and cheesecloth.

4. Apply brushable alodine or cadmium, respectively, to reworked aluminum or steel. Omit this step if material being reworked is stainless steel, titanium, or fiberglass.

5. Mask area to be filled.

6. Mix 2-part filler and apply to damaged area using wooden spatula.

7. Allow filler to cure for time specified. Heat may be used to accelerate cure. Place heat lamp in a manner that heat rays are directed on rework area and temperature at surface is within prescribed range.

   Note: Heat blankets placed over the repair area with a Teflon film sandwiched between may also be used as a heat source to speed curing of filler.

8. Contour reworked area to restore original profile, using hand file and abrasive paper.

9. Touchup repair area using aerosol cans of zinc chromate primer, black paint, and brown paint, as required.

Patch Repair of Small Fiberglass Skin Area.

REPAIR PROCEDURE NO. 3

Note: This repair may be utilized for damaged areas up to 25 sq. in.

1. File or grind away damaged skin using power tools as available. Scarf edges of reworked skin using abrasive paper.

   Note: In cases where compressed air supply is not available, a specially ground, hand held scraper may be used to remove damaged skin.

2. Remove paint from area surrounding scarfed edges using solvent and cheesecloth.

   Note: If applicable, Repair Procedure No. 6 "core-fill of small area" should now be accomplished.

3. Cut and scarf fiberglass skin patch to fit repair area.

4. Clean areas to be bonded using solvent and cheesecloth.

5. Mask area to be bonded.

6. Mix 2-part adhesive and apply to patch and reworked area using serrated spreader.

7. Install patch and retain in place with hi-temp mylar tape.

8. Cover with Teflon film and retain film with mylar tape.

9. Cover with thin aluminum sheet and retain with mylar tape.

10. Cover with heating blanket and retain with mylar tape.

11. Wrap with inflatable bladder and secure with web straps.

12. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

Note: An alternate means of creating bond pressure may be employed by using a sandbag weight over the patch area.

13. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28 volt D.C. power source. Allow adhesive to cure,maintaining prescribed cure conditions for time specified.

14. Remove bladder, aluminum sheet, etc., and sand smooth excess adhesive at patch edges.

15. Touch up repair area using aerosol cans of black paint and brown paint, as required.

16. Refer to repair versus blade balance chart. Remove specified number of balance washers from either or both blade tip locations, as indicated.

Patch Repair of Large Fiberglass Skin Area.

REPAIR PROCEDURE NO. 4.

Note: This procedure is same as Procedure No. 3 except that repair area is greater, accounting for longer average time to accomplish.

This repair may be utilized for damaged areas up to 125 sq. in.

Patch Repair of Small Aluminum Skin Area.

REPAIR PROCEDURE NO. 5

Note: This repair may be utilized for damaged areas up to 2½ inches in diameter or oblong areas 1 inch by 4 inches.

1. Draw a circle around the damaged area just large enough to encompass damage.

2. Remove skin just inside the circled area, disturbing the honeycomb core as little as possible. It is desirable to heat the cutout disc to 200°F (max.) and lift out the disc of skin while heated.

3. Deburr edges of hole, making sure skin is free of scratches and nicks.

4. Remove paint from repair area with cleaner. Dry with a clean cloth. Do not allow cleaner to enter the blade.

5. Prepare a patch to cover the hole that will overlap by 0.75 inch. Patch may be fabricated from 2024-T3 aluminum 0.020 inch thick, and large enough to overlap the hole at least 0.75 inch all around the perimeter. Deburr and blend out edges. Sand the bond area of the patch and blade with 400 grit paper.

6. Clean bond area on patch and blade with cleaner. Dry with a clean cloth.

7. Apply adhesive to patch area around hole and patch. Apply patch to blade, moving patch slightly under pressure, to make sure voids in bond are expelled. Blend out excess adhesive.

8. Cover with Teflon film and retain film with mylar tape.

9. Cover with thin aluminum sheet and retain with mylar tape.

10. Cover with heating blanket and retain with mylar tape.

11. Wrap with inflatable bladder and secure with web straps.

12. Inflate bladder to 5-10 psi using compressed air or hand-operated tire pump.

    Note: An alternate means of creating bond pressure may be employed by using a sandbag weight over the patch area.

13. Provide electric power to heating blankets using auxiliary power unit (APU) or other 28 volt D.C. power source. Allow adhesive to cure, maintaining prescribed cure conditions for time specified.

14. Remove bladder, aluminum sheet, etc., and sand smooth excess adhesive at patch edges.

15. Touch up repair area using aerosol cans of black paint and brown paint, as required.

16. Refer to repair versus blade balance chart. Remove specified number of balance washers from either or both blade tip locations, as indicated.

Core-Fill of Small Area.

REPAIR PROCEDURE NO. 6

Note: This repair supplements Repair Procedure No. 3, when required.

1. To the extent practicable, remove damaged honeycomb using knife and scissors.
2. Mix 2-part adhesive and apply to reworked core area using wooden spatula.
3. Place heat source in a manner that heat is directed on rework area and temperature at surface is within prescribed range. Allow adhesive to cure for time specified.
4. Contour reworked area to restore original profile using abrasive paper.

Core-Fill of Large Area.

REPAIR PROCEDURE NO. 7

Note: This procedure is same as Repair Procedure No. 6, except that repair area is greater, accounting for longer average time to accomplish.

This repair supplements Repair Procedure No. 4, when required.

TABLE XXIII. REPAIR KIT CONTENTS

Item No.	Item	Description	Blend Repair Kit No. 1	Fiberglass Patch Kit No. 2	Aluminum Patch Kit No. 3
1	Sand Paper	Sheet, 9 in. sq., 180 grit	2	2	2
2	Sand Paper	Sheet, 9 in. sq., 240 grit	2	8	4
3	Sanding Disc	1-1/2 in. dia. (used with air motor)		2	
4	Cheesecloth	18 in. wide (qty. indicated in ft.)	10	16	12
5	MEK Solvent	Pint Can	1	1	1
6	Cotton Gloves	Pair, Lightweight		1	1
7	Mixing Cup	Quart Size, Paper	2	3	2
8	Wooden Spatula	Tongue Depressor	1	2	1
9	Serrated Spreader	Contractor made		1	1
10	Masking Tape	Roll, 1 in. wide	1	1	1
11	Hi-Temp. Mylar Tape	2 in. wide (qty. indicated in ft.)		5	5
12	Teflon Film	Sheet, transparent, .0005x20x40 in.		1	1
13	Aluminum Sheet	Sheet, .010 x 20 in. square		1	1
14	Brush	1/4 in. wide	1		1
15	Alodine, Brushable	1 oz. bottle	1		1
16	Zinc Chromate Primer	3 oz. aerosol can	1		1
17	Paint, Brown	3 oz. aerosol can	1	1	1
18	Paint, Black	3 oz. aerosol can	1	1	1
19	Preimpregnated Skin	Sheet, 4 ply, 120 cloth, 8 x 16 in.		1	
20	Aluminum Alloy Skin	Sheet, .020 x 6 in. square			1
	Adhesive EC 2216	Special 2-section plastic package	1	1	1
	Corfil 615	Special 2-section plastic package		1	

Note: The last two items are required as indicated, but not included in kits due to limited shelf life.

TABLE XXIV. EQUIPMENT LIST

Item No.	Equipment Description	Blend Repair Kit No. 1	Fiberglass Patch Repair Kit No. 2	Aluminum Patch Repair Kit No. 3
1	Heating Blanket (12 in. x 12 in.)		2	1
2	Inflatable Bladder with Straps		1	1
3	Tire Hand Pump (or compressed air)		1	1
4	Tire Pressure Gage		1	1
5	Scissors		1	
6	28-Volt D.C. Power Source		1	1
7	Scraping Knife		1	
8	Die File	1		
9	Flat File			1
10	Circle Compass			1
11	Electric Heat Gun			1
12	Hacksaw			1
13	4-inch-Long Knife			1

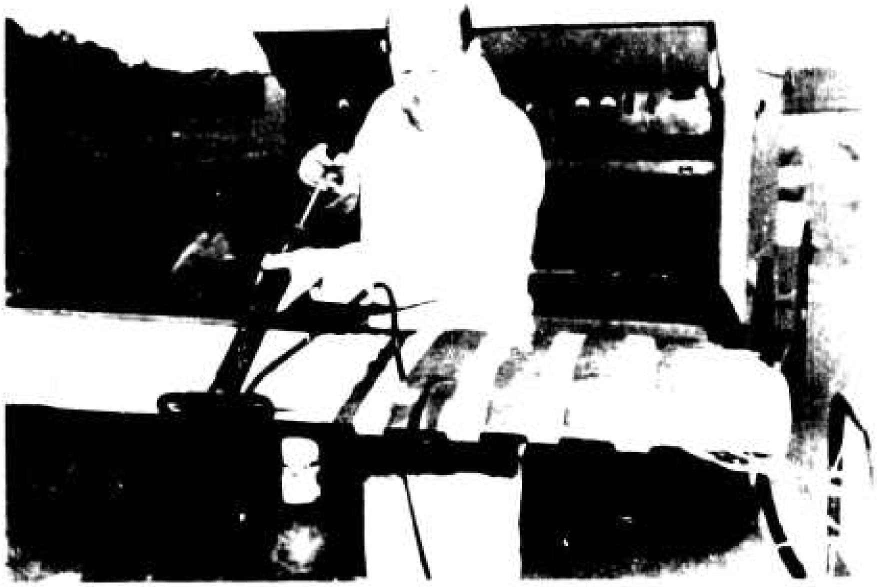

Figure 51. Inflatable Rubber Bladder in Use.

APPENDIX IV

UH-1H ROTOR BLADE DESIGN COST COMPARISONS

The following cost model values are being supplied by the Government to standardize the various rotor blade comparisons. The current UH-1H rotor blade values are listed together with values of the candidate blade that are considered relatively insensitive to variations in design. Where values of the candidate blade are not supplied, they are to be developed by the Contractor for use after approval by the Government Contracting Officer.

	Current UH-1	Candidate
Blade Life Hours	2500	-
Aircraft Life Hours	5000	Same
Aircraft Fleet Size	500-1000-2000	Same
Aircraft Attrition	Zero	Same
Blade Set Attrition	.0003/Flight Hr.	Same
Time of Blade Initiation	Original Production	Same
Cost of One Blade	$3000	-
Experience Curve Position	10,000 Blades	Same
Blade Spares Inventory	30% of Installed	-
% Inherent Damage	29.2%	-
% External Damage	70.8%	-
Blade Time Between Inherent Damage	547 Hours	-
Blade Time Between External Damage	400 Hours	Same
Repair Performance Degradation	Zero	Same
Cost Field, Org. Mil. Labor Per Hour	$4.00	Same
% Military Labor, Field	100%	Same
Field Overhead & Support Cost	Zero	Same
MMH Each Blade Removal	3.75	Same
MMH Disposition, Inspect	1.5	Same
MMH Repair, Field	-	-
Parts Material Cost/Repair(Fld)	$5.00	-
GSE, Tooling Cost/Repair (Fld)	Zero	-
MMH Obtain Replacement Blade	3.0	Same
MMH Ops, Inventory, Requisition	3.0	Same
MMH Blade Installation	3.75	Same
% Field Repairs Require Removal	100%	-
% Removed Blades Scrapped, Org.	30%	-
% Removed Blades Repaired, Org.	12%	-
% Removed Blades to Depot Repair	58%	-
% Depot Received Blades Scrapped	68%	-

	Current UH-1	Candidate
% Depot Received Blades Overhauled	32%	-
Shipping, 8000 Mi, Surface, Blade	$90	Same
Shipping, 8000 Mi, Surface, M-T Container	$45	Same
Rotor Blade Container, Reusable	$200	Same
Preparation for Shipping, Field	$70	Same
% Surface Shipping to CONUS	100%	Same
% Mil Air Shipping from CONUS	100%	Same
8000 Mi Mil Air Shipping	$130	Same
% Civilian Labor, Depot	100%	Same
Composite Civilian Labor Cost, Per Hour	$12	Same
Blade Overhaul Cost, Depot	$925	-
Depot Overhead & Support Cost	Zero	Same
MMH Receive, Unpack, Depot	1.0	Same
MMH Inspect (100% of Rec'd), Depot	1.5	Same
MMH to Dispose of Scrap, Depot	.5	Same
Preparation for Shipping, Depot	$70	Same
Shipping Containers Required	30% of Installed	-

NOTES:

a. Develop R&D, prototype and production candidate blade costs, determine learning curve equation, assume previous production of 10,000 units and establish cost at 10,000th unit for use in cost model and comparison with current UH-1H blade.

b. Conduct 3 separate cost runs for each fleet size, 500 - 1000 - 2000.

c. Aircraft utilization is 500 hours/year for 10 years, 5000 hour life.

d. Zero aircraft attrition permits the fleet size to remain constant throughout the analyses. Replacing the blade sets at a rate of .0003/flight hour accounts for the new sets of blades required as a result of attrition.

e. External damage is further characterized by the following rates:

Battle Damage	16.0%
Dent	25.4%
Foreign Object Damage	16.0%
Puncture	18.8%
Tear	8.0%
Overstress	15.8%

APPENDIX V

DEVELOPMENT PLAN FOR EXPENDABLE MAIN ROTOR BLADES

INTRODUCTION

This appendix presents the plan for development of the recommended expendable main rotor blade concept. The proposed plan includes sufficient test substantiation to justify preliminary service trials of the blade on a quantity of UH-1H helicopters in simulated field conditions. It is intended that this program will provide sufficient background and experience in the application and use of expendable rotor blades that this general concept may be made a requirement on future Army procurements involving large quantities of rotor blades.

DISCUSSION

The following development plan is presented for the purpose of demonstrating in service the principles of the expendable main rotor blade and the savings that are attainable with this concept. The plan provides for sufficient test and substantiation of the blade to permit flying of a quantity of blades by service pilots for the purpose of obtaining an evaluation of the design under field conditions. The complete plan evaluates all aspects of the application of expendable blades to a fleet of helicopters including virtually all of the economic influences.

DEVELOPMENT PLAN

The plan includes six basic phases: design and analysis, tooling, bench test, whirl test, flight test, and service evaluation. A detailed description of each of these phases follows.

It should be noted that the tooling and fabrication costs are based on Design 2 (Figure 3) of the study, the formed sheet stainless steel concept. These costs would be somewhat less for Design 1.

Design and Analysis

The design and analysis phase makes maximum utilization of the work completed on the present program. Detailed design and complete analytical support however will require further effort to provide complete definition. Detailed drawings of all components, dynamic analysis of all significant flight conditions and flight loadings, and stress analysis for all critical conditions are included in this phase. The analysis must define static strength requirements for limit-load conditions and also fatigue strength requirements for all steady-state flight conditions.

Tooling

The tooling designed for this program should be permanent tooling capable of producing a quantity of blades at a low rate. Automation of processing is not justifiable at this time. The approach should anticipate a significant amount of skilled hand labor and should therefore minimize the number and complexity of tools. Following fabrication, the tools should be evaluated in terms of the quality of the product they produce by destructive test of a sufficient quantity of blades or components to demonstrate a high level of consistent quality. Destructive test of at least four samples of each bond joint is anticipated. Tooling developed here should provide an excellent basis for the design of hard production tools on a subsequent program.

Bench Test

This phase of the program provides for static and fatigue test substantiation of the blade structural design. The static test plan will include application of limit loads to a blade root specimen including the root reinforcement, the transition section, and a short length of basic outboard airfoil section. This test should include centrifugal force, flatwise bending, and edgewise bending. After achieving limit load, the specimen will be unloaded and then loaded to failure.

Fatigue tests of at least two root specimens and two outboard basic airfoil sections are anticipated. The blade root specimens will be similar to that used for the static test, and will have vibratory flatwise and edgewise bending superimposed on a steady centrifugal force. One test will be run out to 10^7 cycles at a load level representing high speed level flight, and the other will be tested at high vibratory levels to failure. After run-out, the lower stress specimen will be typically damaged and the test repeated to failure. One outboard specimen shall be tested in flatwise bending and one in edgewise bending, at vibratory moments representative of high speed level flight. After achieving 10^7 cycles, each specimen will receive typical service damage and will then be retested to determine damage tolerance and crack propagation rates.

Whirl Test

A pair of new rotor blades should be whirl tested for 150 hours with representative cyclic and collective control inputs. Following completion of this test, a demonstration of the survivability of the design should be undertaken. This would include inflicting damage statically to the blade, rotating it, and evaluating the resulting unbalance, out-of-track, or other behavior. The result of this behavior on a flight vehicle should be estimated.

Flight Test

Flight test of the expendable main rotor blade concept should include a strain survey, limited structural demonstration, flying qualities, and performance evaluation. The strain survey should cover all portions of the flight envelope that are important to an assessment of the fatigue life of the rotor blade including the maneuver spectrum. Structural demonstrations should be flown in such a way as to demonstrate only the approved load factor-airspeed flight envelope of the UH-1H helicopter with adequate build-up to insure that blade loads and stresses are within the strength capabilities of the blade. General flying qualities, vibration and performance should be compared to published data for the present UH-1H blade.

At the end of the flight test program, a data review and analysis phase is included. This phase is to review data from all phases of the program and evaluate the suitability of the expendable main rotor blade for flight by service pilots in an accelerated service evaluation. One of the key elements in this evaluation will be a calculation of the fatigue life of the blade for the UH-1H flight spectrum. Any deviations from this spectrum anticipated in the accelerated service trials shall also be investigated. A report with recommendations for future effort shall be produced as a result of this phase.

Service Evaluation

The service evaluation of the expendable main rotor blade concept should be conducted by Army personnel at a facility selected by the Army. The contractor will supply five ship sets of rotor blades with spares and also a sufficient quantity of repair kits and materials. Technical advice and assistance shall be provided by the contractor, at least at the outset of the service evaluation. The details and duration of the evaluation should be jointly agreed to by the contractor and the Army. Final results and conclusions to be drawn from the service evaluation shall be the responsibility of the cognizant Army technical personnel.

TABLE XXV. DEVELOPMENT SCHEDULE - EXPENDABLE MAIN ROTOR BLADE

TASK

1. DESIGN AND ANALYSIS
   - DETAIL DESIGN
   - DYNAMIC ANALYSIS
   - CALCULATE FLIGHT LOADS
   - STRESS ANALYSIS
   - SURVIVABILITY ANALYSIS
   - MAINTAINABILITY ANALYSIS
2. TOOLING
   - TOOL DESIGN
   - TOOL FABRICATION
   - TOOL TRYOUT
3. BENCH TEST
   - TEST RIG DESIGN AND FABRICATION
   - TEST SPECIMEN FABRICATION
   - STATIC TESTS
   - FATIGUE TESTS: BASIC DESIGN
   - DAMAGE TOLERANCE
4. WHIRL TEST
   - BASIC SUBSTANTIATION
   - SURVIVABILITY DEMONSTRATION
   - REPAIRS
5. FLIGHT TEST
   - NEW BLADES: STRAIN SURVEY, STRUCTURAL DEMO.
   - FLYING QUALITIES, PERFORMANCE
   - REPAIRED BLADES: COMPARATIVE QUALITIES
   - DATA REDUCTION AND ANALYSIS
   - MAINTAINABILITY ANALYSIS
6. SERVICE EVALUATION
   - FIVE SHIP SETS DELIVERED TO ARMY
   - ACTIVITY FOR EVALUATION UNDER SIMULATED FIELD CONDITIONS

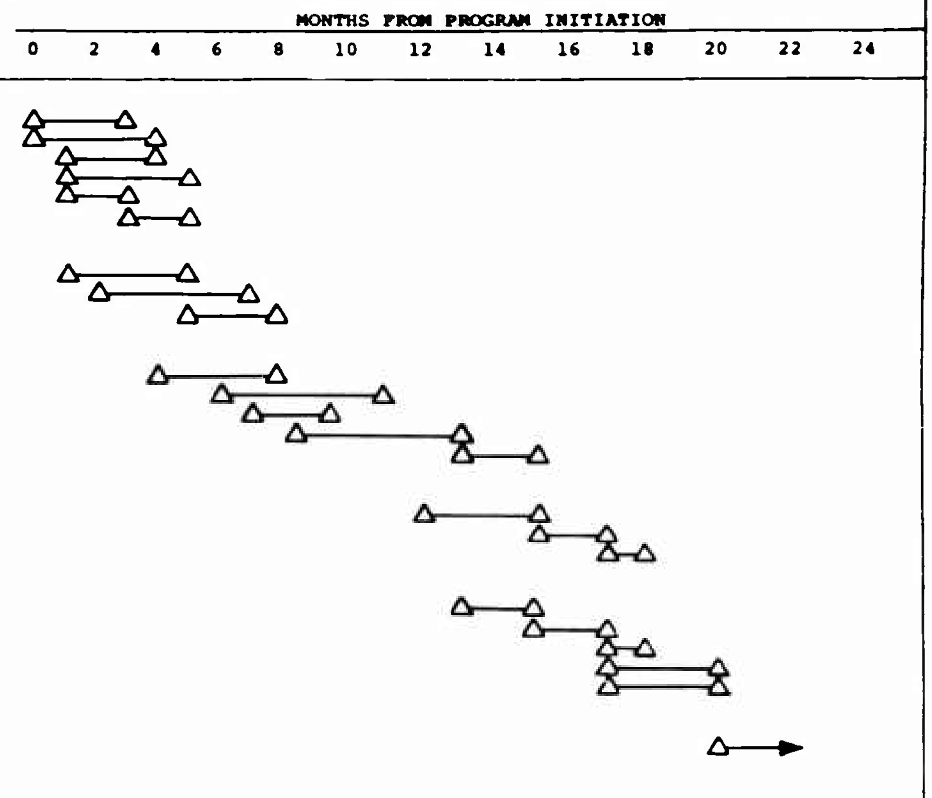

TABLE XXVI. ESTIMATED MANHOUR DISTRIBUTION - EXPENDABLE MAIN ROTOR BLADE																					
	MONTHS FROM PROGRAM INITIATION																				
TASK	0		2		4		6		8		10		12		14		16		18	20	TOTALS
1. DESIGN AND ANALYSIS																					
DETAIL DESIGN	960	960	960																		2880
DYNAMIC ANALYSIS	160	160	160	160																	640
FLIGHT LOADS		160	160	160																	480
STRESS ANALYSIS		160	160	160	320																800
SURVIVABILITY ANALYSIS		160	320																		480
MAINTAINABILITY ANALYSIS				320	320																640
2. TOOLING																					
TOOL DESIGN		320	320	320	320																1280
TOOL FABRICATION			2080	2080	2080	2080	2080														10,400
TOOL PLANNING AND TRYOUT						800	800	800													2400
3. BENCH TEST																					
TEST RIG DESIGN AND FABRICATION					480	480	480	480													1920
TEST SPECIMEN FABRICATION							1420	1420	160	160	160										3320
STATIC TESTS								640	640	320											1600
FATIGUE TESTS:																					
BASIC DESIGN									320	640	640	640	640								2880
DAMAGE TOLERANCE														640	640						1280
4. WHIRL TEST																					
BLADE FABRICATION									1420												1420
BASIC SUBSTANTIATION													640	640	640						1920
SURVIVABILITY DEMONSTRATION																640	640				1280
REPAIRS																		640			640
5. FLIGHT TEST																					
BLADE FABRICATION										1420	1420										2840
FLIGHT TEST (NEW BLADES)														2240	2240	2240	2240				8960
FLIGHT TEST (REPAIRED BLADES)																		2240			2240
DATA REDUCTION AND ANALYSIS																		800	800	800	2400
MAINTAINABILITY ANALYSIS																		320	320	320	960
6. SERVICE EVALUATION																					
BLADE FABRICATION												1420	1420	1420	1420	1420					7100
DELIVERY																				40	40
TOTALS	1120	1920	4160	3200	3520	3360	4780	3340	2220	2860	2220	2060	2700	4940	4940	4300	2880	4000	1120	1160	60,800

TABLE XXVIII. DEVELOPMENT COSTS-EXPENDABLE MAIN ROTOR BLADE

TASK		ESTIMATED COST
1.	DESIGN AND ANALYSIS	$ 125,000
2.	TOOLING	358,000
3.	BENCH TEST	185,000
4.	WHIRL TEST	83,000
5.	FLIGHT TEST	317,000
6.	SERVICE EVALUATION	119,000
	TOTAL	$1,187,000

RECOMMENDATIONS

It is recommended that the development plan defined here be undertaken for the purpose of demonstrating the feasibility, practicality, and cost effectiveness of the expendable main rotor blade concept. As a result of conducting this program, it will be possible for the Army to specify with confidence the characteristics that are attainable in future rotor blades and the benefits that will be derived through this approach.